Boulder River Watershed

Irrigation Efficiencies and Water Supply Study 2003-2006

Montana Department of Natural Resources and Conservation and Boulder River Watershed Association

DNRC Report: WR 2.D.7a BRW Boulder River Watershed
Helena, Montana
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Summary

Introduction

The Boulder River Watershed Association and the Montana Department of Natural Resources and Conservation conducted a study of irrigation efficiencies and water supplies in the Boulder River watershed during the 2003 through 2006 irrigation seasons. Existing irrigation efficiencies were evaluated and potential improvements that could be made identified. The study also evaluated the water supply of the Boulder River and its major tributaries to determine where efficiency improvements would be most beneficial to offset water shortages and to improve streamflows. The study consisted of the following three basic components:

- A watershed irrigation inventory
- Streamflow measurement
- Ditch loss and field irrigation efficiency assessments

Irrigated Lands Inventory

Irrigation in the watershed was mapped and characterized with a computerized geographic information system (GIS). This included identifying (1) irrigated lands, (2) the types of irrigation systems used, and (3) the ditches and water sources that supplied the irrigated lands. About 12,700 acres of land were found to be irrigated with water from the Boulder River and its tributaries. As of 2005, about 87 percent of it was flood irrigated, and the remaining 13 percent was sprinkler irrigated. Gated pipe was being used on about 20 percent of the flood irrigated land in the watershed. The trend to more efficient irrigation was evident during the study, with new gated-pipe systems and sprinkler irrigation systems installed each year. About 40 percent of the land irrigated with Boulder River water is topographically within the Yellowstone River Valley, just to the east and west of Big Timber.

Streamflow Measurement and Water Supply

Streamflows in the watershed were monitored at seven gaging stations. About 60 percent of the flow of the Boulder River originates from the upper main Boulder River, with the West Boulder River contributing about 30 percent and the East Boulder the remaining 10 percent. During the 2003-2006 May-through-September irrigation seasons, the Boulder River watershed produced an average of about 280,000 acre-feet of water each season. About 42,000 acre-feet of this water was consumed by irrigation or diverted to irrigate adjacent lands in the Yellowstone River Valley. Streamflow reductions during the irrigation season were small in the upper Boulder River, and the middle sections of the Boulder River were found to be gaining about 20 cubic feet per second (CFS) from irrigation return flows. Irrigation withdrawals typically reduced flows by about 100 to 150 CFS in the lower five miles of the Boulder

River. Irrigation depletions on the West Boulder River generally were in the 20-to-40 CFS range. Irrigation on the East Boulder River typically uses about 30-to-50 CFS of water, and the stream often is dewatered late in the summer when irrigation demands exceed the water supply.

Irrigation Efficiencies

Measurements were made on 13 ditches in the watershed to assess losses due to seepage and other factors; the total length of ditch evaluated was about 45 miles. These 13 ditches provide water to about one-third of the irrigated land in the watershed. Ditch losses averaged about 28 percent, but there was much variability with ditch loss ranging from zero percent to about 80 percent of the water diverted.

Field irrigation efficiency assessments were conducted on five flood irrigated fields in the watershed. Ranchers were found to apply an average of about 20 inches of water to a set during an irrigation. Of the 20 inches applied, about 4 inches on average was stored in the soil and would be available for crop use. A little less than 4 inches of the applied water on average ran off the end of the field as tail water. The remaining 12 inches of the original 20 inches applied was estimated to have percolated below the root zone and to the water table. It is likely that most of this water will eventually return to a stream. Average field efficiencies were 23 percent, but ranged from 15 to 42 percent.

Overall, for each acre-foot of water consumed by crops through evapotranspiration in the Boulder River watershed about six acre-feet of water is diverted from the stream at the headgate. This results in an average efficiency of about 17 percent. This approximate efficiency was substantiated by an analysis of canal loss measurements, field efficiency assessments, and streamflow data. It was estimated that irrigation in the watershed consumes through evapotranspiration an average of about 1.1 acre-foot of water per acre irrigated.

Recommendations

East Boulder River

Almost all the irrigation in the East Boulder River watershed is flood irrigation and efficiencies are low overall. Improving ditch and field irrigation efficiencies could improve the water supply for junior water users. Some of the water that is diverted from the East Boulder River is used to irrigate land that is adjacent to the Boulder River proper. Efficiency improvements on these irrigated lands and supply ditches might improve flows in the lower East Boulder River by reducing diversion requirements. Seepage losses on the Craft Ditch were estimated at over 60 percent and could be reduced through ditch repair or lining. Efficiency improvements alone probably would not be sufficient to keep the East Boulder

River from being dewatered during the late summer of dry years because the water demand is much higher than the water supply.

West Boulder River

Ditch losses were found to be moderate-to-high in the West Boulder River watershed. Although much of the water lost through ditch seepage probably returns to the West Boulder River, the losses could result in less than optimal water deliveries to fields at the lower end of a ditch system. Controlling losses through ditch repairs and possibly lining some segments could result in a better water supply for irrigators and improved crop yields. Almost all the irrigation in the West Boulder River watershed is flood irrigation and efficiencies are low overall.

Main Boulder River

In the Boulder River Valley, irrigation efficiencies generally are low. The water supply for lands in the Boulder Valley usually is not limiting, but improving field efficiencies could increase hay yields and potentially improve the water supply for the most distant water users on a shared ditch system.

Seepage losses from the lower Boulder River ditches were found to be moderate to high. These losses could be reduced through repairs, lining, or by periodically sealing the ditches with polymer-type sealers. Water savings could be used to decrease shortages that might occur at fields near the lower ends of some of the ditches; or some of the saved water could be left in the river to improve flows for fisheries in the lower Boulder River. Most of the land irrigated with water from the lower Boulder River is flood irrigated and efficiencies are likely low overall. Because return flows from much of the irrigation with lower Boulder River water go to the Yellowstone River, water savings through improved efficiencies on these systems could reduce diversion requirements at the headgate and thereby improve streamflows in the lower Boulder River.

Overall

Many ditches were found to be in poor repair; grades were often low and there were areas where water was backing up due to undersized culverts or constriction at other types of crossings. Where a ditch is constricted, water backs up and seepage is increased. Improving crossings and bringing ditches back to grade could decrease seepage losses. Polymer sealers are another way to control ditch losses, although there are environmental concerns that may need to be addressed before they are used. These are sprayed on each year in the spring before the ditch is turned on.

Some river headgates were found to be in poor condition and there seldom were water measuring devices at the headgates or further down on the ditches. By giving the users the ability to control their diversions and to monitor water usage, improved headgates and measuring devices could lead to more efficient water use and better water distribution between users on shared ditches.

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Glossary and Abbreviations

Association: The Boulder River Watershed Association

Cubic feet per second (CFS): A unit of measure of the flow rate of water in a stream, river, ditch or pipe. A CFS is equivalent to a flow of 7.48 gallons per second, or 449 gallons per minute. 1 CFS is equivalent to 40 miner's inches in Montana.

DNRC: The Montana Department of Natural Resources and Conservation

Evapotranspiration (ET): The water which is transpired by plants (usually through the leaves) plus that evaporated from the soil and plant surface.

Gaging station: A station on a stream where the flow of the stream is continuously measured. Usually it contains an instrument that measures and logs water levels. Flow measurements are also made periodically at the station (usually in CFS) in order to calibrate water levels to streamflow.

Geographic Information System: A computer program and data base application that is used to store, analyze and map geographic information.

Miner's inch: A unit of water flow measurement that is commonly used by Montana irrigators. 40 miner's inches in Montana are equivalent to 1 CFS.

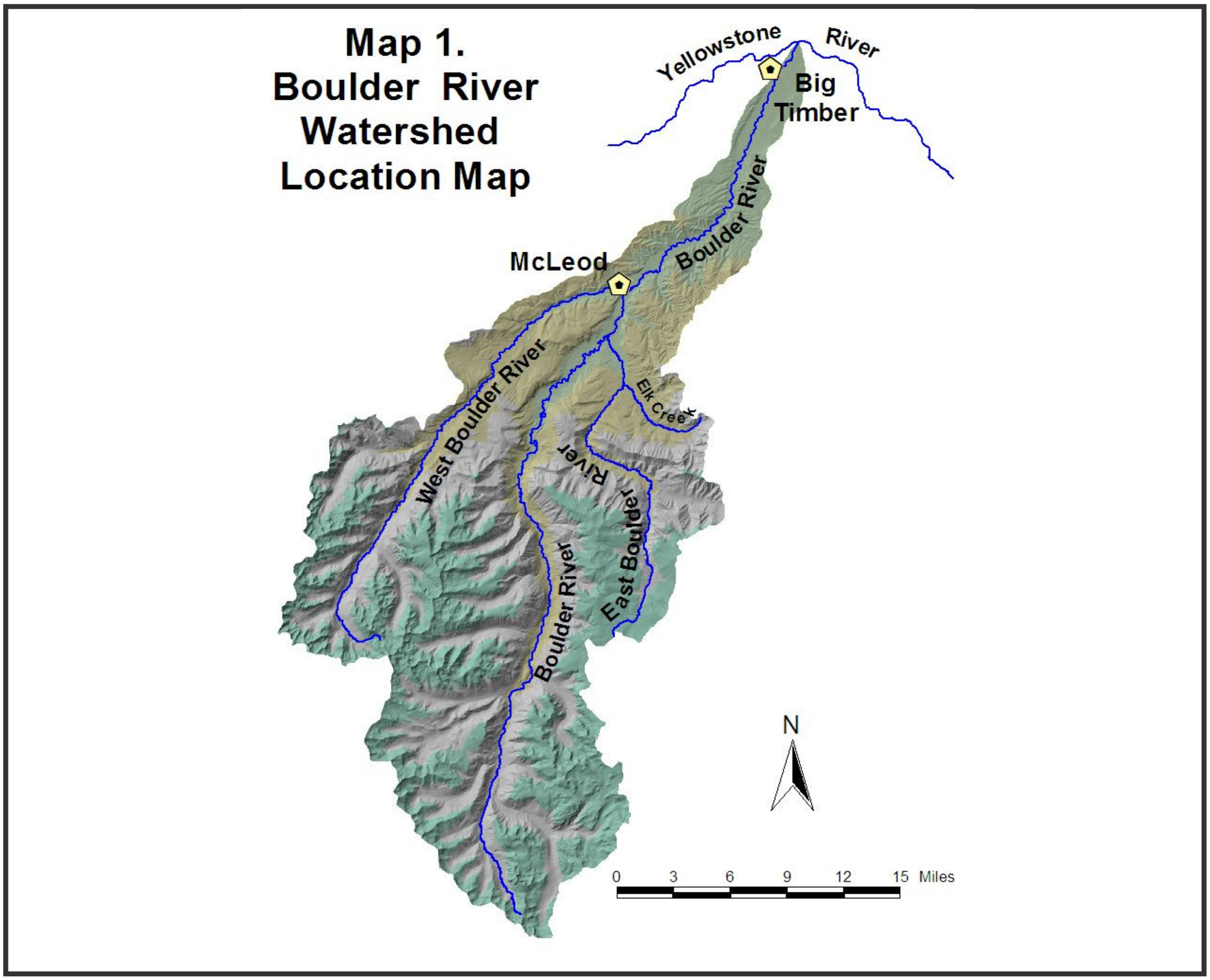
NRCS: The United States Department of Agriculture, Natural Resources Conservation Service.

Phreatophyte: A plant that obtains most of its water from shallow aquifers. Phreatophytes often have high water requirements and usually are found where the water table is high, such as near streams, wetlands, or leaky irrigation ditches.

USGS: The United States Geological Survey; a Federal agency whose duties include maintaining a nationwide streamflow measurement and monitoring program.

Introduction

The Boulder River Watershed Association is a group of local citizens that are interested in the management of natural resources in the watershed. The Association is supported with funding and technical assistance by the Sweet Grass Conservation District, Stillwater Mining Company, and State and Federal Agencies. The Association's area encompasses the Boulder River Watershed, which is a tributary to the Yellowstone River near Big Timber, Montana (Map 1).



The focus of this study is irrigation water management. About 12,700 acres of land are irrigated with water from the Boulder River and its tributaries. Ranchers in the Boulder River Watershed want to use irrigation water effectively and efficiently. The Association also is interested in minimizing soil erosion and sediment carried to streams from irrigation runoff. In addition, the Association would like to improve streamflows for fish and wildlife, and improving irrigation efficiencies is seen as a potential way to achieve all of these goals.

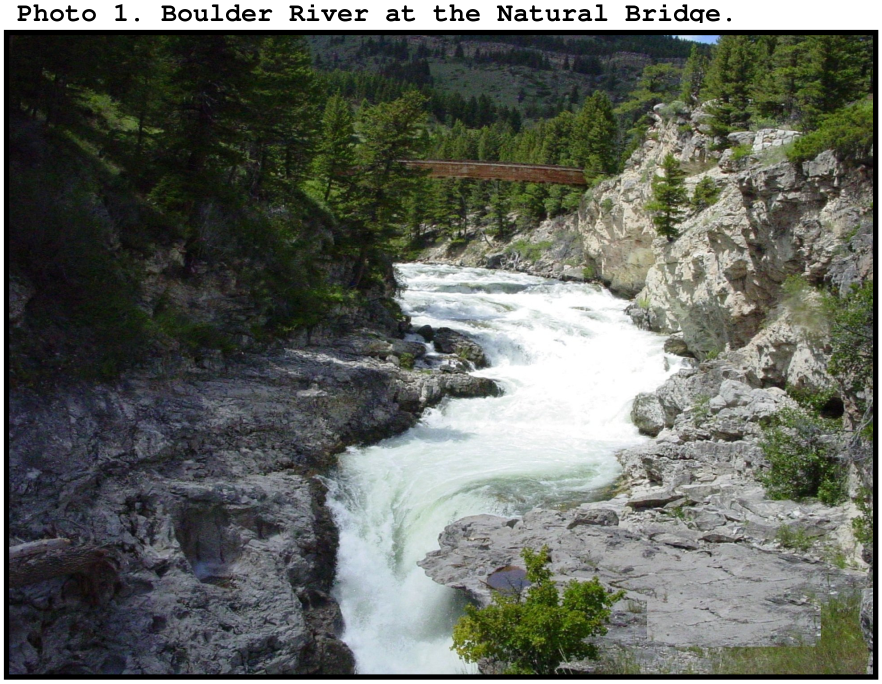
The Association's goals for this study were to characterize existing irrigation efficiencies, to identify improvements that could be

made, and to prioritize locations in the Watershed where efficiency improvements are most needed and would be most beneficial. To date, the Association has helped many landowners replace tarp dam flood irrigation systems with gated pipe. The Association also has experimented with some canal lining projects.

General Basin Description

The Boulder River is a southern tributary of the Yellowstone River. The drainage area of the Watershed is about 525 square miles. The southern portion of the Boulder River Watershed is dominated by the Absaroka Range to the west of the river, and the Beartooth Range to the east. These mountains are mostly forested and the highest elevations contain extensive alpine meadows. There are peaks and plateaus in the mountains that are above 10,000 feet, where snow persists until late summer. The Boulder River abruptly exits these mountains at the Natural Bridge (Photo 1).

Photo 1. Boulder River at the Natural Bridge.



Flowing north, the Boulder River enters a valley bordered by hills and which contains extensive glacial deposits, such as moraines and outwash features. Where the valley is not irrigated, grasses and shrubs are the predominant vegetation with a belt of riparian vegetation bordering the streams. In the valley near McLeod, the Boulder River is joined by its two major tributaries: the East Boulder River and West Boulder River. Near Big Timber, the Boulder River joins the Yellowstone River; the elevation at the confluence is approximately 4,000 feet.

Annual average precipitation in the watershed ranges from about 15 inches at Big Timber, to more than 40 inches in the highest elevations. Because the higher elevations receive most of the precipitation and are cooler, they produce most of the water that flows in the streams. Valley lands are much drier and must be

irrigated to produce the consistent crops of hay which are used for winter cattle feed by the ranching operations in the watershed and surrounding area. Irrigation, long summer daylight hours, and abundant sunshine produce lush crops of grass and alfalfa hay in the watershed. Typical seasonal hay yields for irrigated lands are from two to four tons per acre.

Water diverted from the Boulder River through the irrigation ditches not only supplies land in the Boulder River Valley, but also is conveyed to irrigate lands that are topographically in the Yellowstone River Valley, just to the west and east of Big Timber. Similarly, some of the water diverted from the West and East Boulder River is used to irrigate land adjacent to the Boulder River proper.

Project History and Scope of Work

During the spring of 2002, the Association asked the Montana Department of Natural Resources and Conservation (DNRC) if it would assist with a project to investigate irrigation efficiencies in the watershed. DNRC and the Association met in May of that year and identified the following tasks for a potential irrigation efficiency and water supply study:

- Conduct an irrigated land inventory
- Monitor streamflows to determine water supplies and water use
- Assess ditch losses and field irrigation efficiencies

The Association and DNRC determined that the project might take three or four field seasons to complete, depending on the water supply conditions during those years. It was thought that, over a three or four year period, there might be a combination of wet, moderate and dry years, and that data from a variety of years would capture the variability of water supply conditions in the watershed. At the time, the Association and DNRC realized that it was too late in the season to start field work for the projects during 2002. Instead, the Association applied for grant funding during the winter of 2002-2003, which was obtained and used to cover some project costs and to hire a part-time student intern to work on the project during the summers. DNRC was able to commit staff time, equipment, and some travel funding to the project.

DNRC began working on the irrigated lands mapping aspects of the project during the early spring of 2003. Field work on the project began during May of that same year with the installation of the stream gaging stations. Field work for the project was started each spring and continued into October. Because the first three field seasons were drier years, the Association and DNRC decided to continue the stream gaging aspects of the project for another irrigation season, hoping to collect data for a wetter year. Unfortunately, 2006 turned out to be another dry year. The final data compilation, analysis, and work on this report was done during 2007.

Irrigated Lands Inventory

Background

Irrigation from the Boulder River began during the late 1800s with most of the major ditches being constructed from about 1880 to 1905. Ditches were dug to provide water by gravity to flood-irrigated fields. There are some relatively small ditches that carry water a short distance from the river to irrigate just a couple of fields. Others are quite large and transport water for miles to irrigate many acres. The largest ditch, the Dry Creek Canal, supplies water to over 3,000 acres of irrigation.

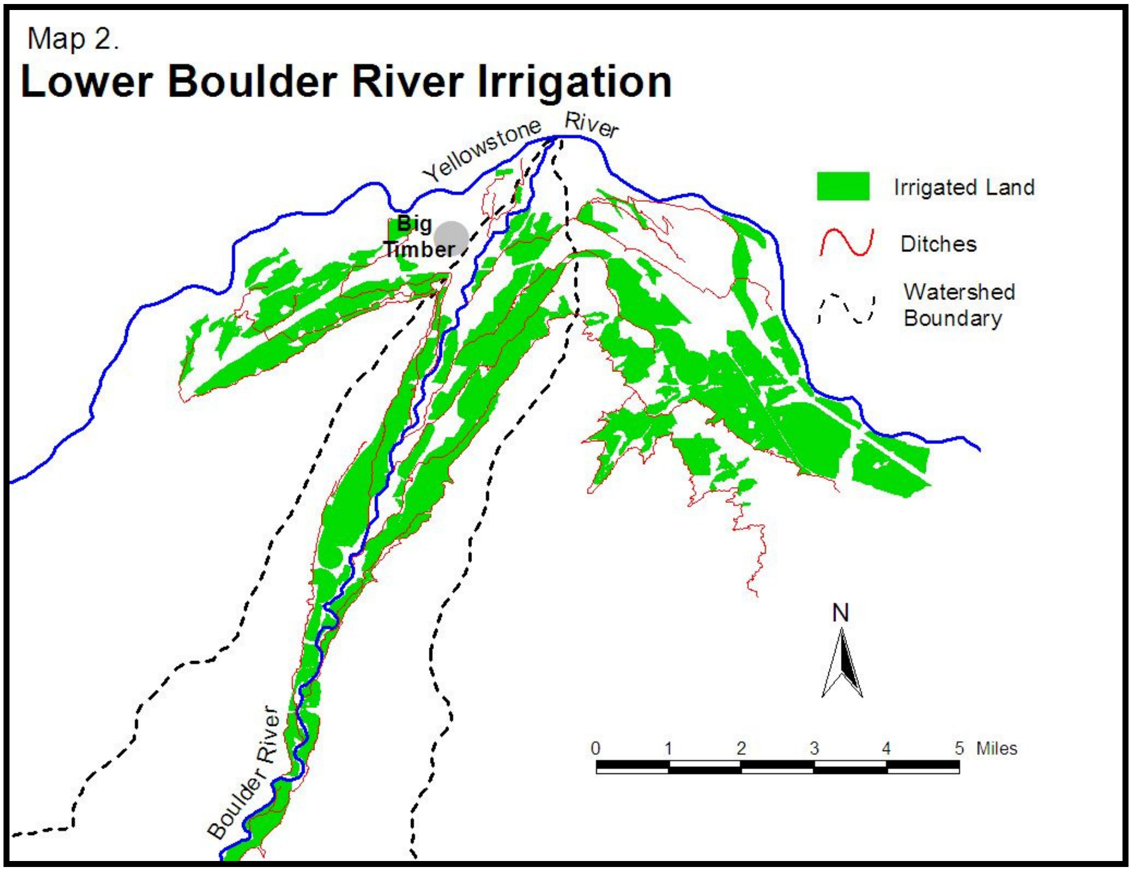
The first comprehensive inventory of irrigated land in the area was the Sweet Grass County Water Resources Survey that was conducted in the 1940s by the State Engineers Office (State Engineers Office 1950). The Survey identified about 13,300 acres as actively irrigated with water from the Boulder River Watershed. Of these acres, about 1,200 were supplied with water from the West Boulder, 1,700 from the East Boulder drainage(including Elk Creek), and the remaining 10,400 acres from the Boulder River proper, including small amounts from minor tributaries. The many ditches in the watershed also were mapped and identified in the Survey.

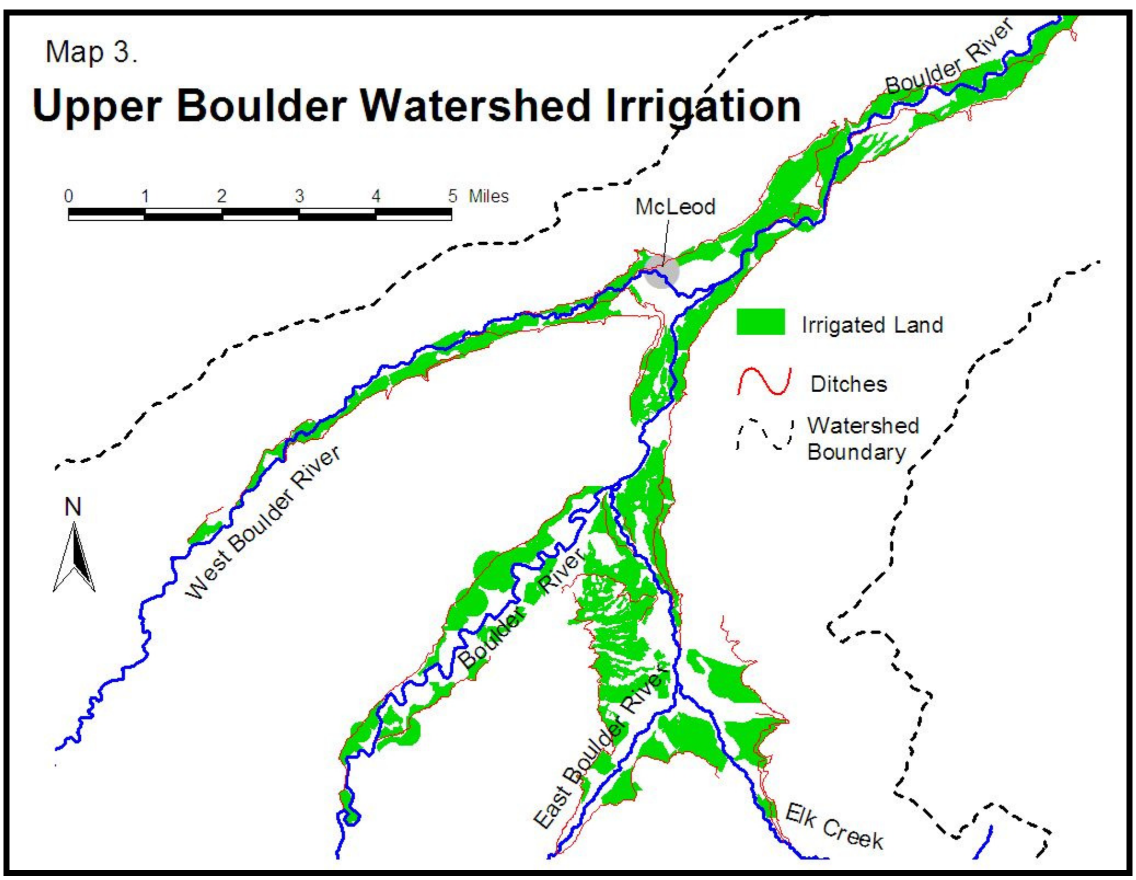
Geographic Information System

To determine the current status of irrigation in the watershed, DNRC and the Association put together a computerized geographic information system (GIS) irrigation inventory. The purpose of the GIS inventory was to map what lands were being irrigated, the type of system they were being irrigated with, and to identify the ditches supplying the irrigated land and water sources for these ditches. Base maps used for the GIS inventory were ortho-photo quadrangles (aerial photographs transposed to conform to the boundaries of USGS 7.5 minute quadrangle maps) from the late 1990s. The 1950 Water Resources Survey also was used as a guide to locate and identify the major ditches that supply the irrigated land.

With this information, initial irrigation maps were compiled and field checked by the student intern during the summer of 2003. To further recheck the analysis, color and color-infrared aerial photographs from the summer of 2005 were examined and corrections and updates made. Notwithstanding all the checking and rechecking, there probably still are some inaccuracies in the irrigated land designations. For instance, although it is easy to discern a center pivot irrigation system on an aerial photograph, it can be easy to confuse low-efficiency wild flood irrigated fields with surrounding sub-irrigated wet meadows and vice-versa. Also, because some landowners are upgrading their irrigation systems, the mapped system as of 2005 may not be the same as the system being used today.

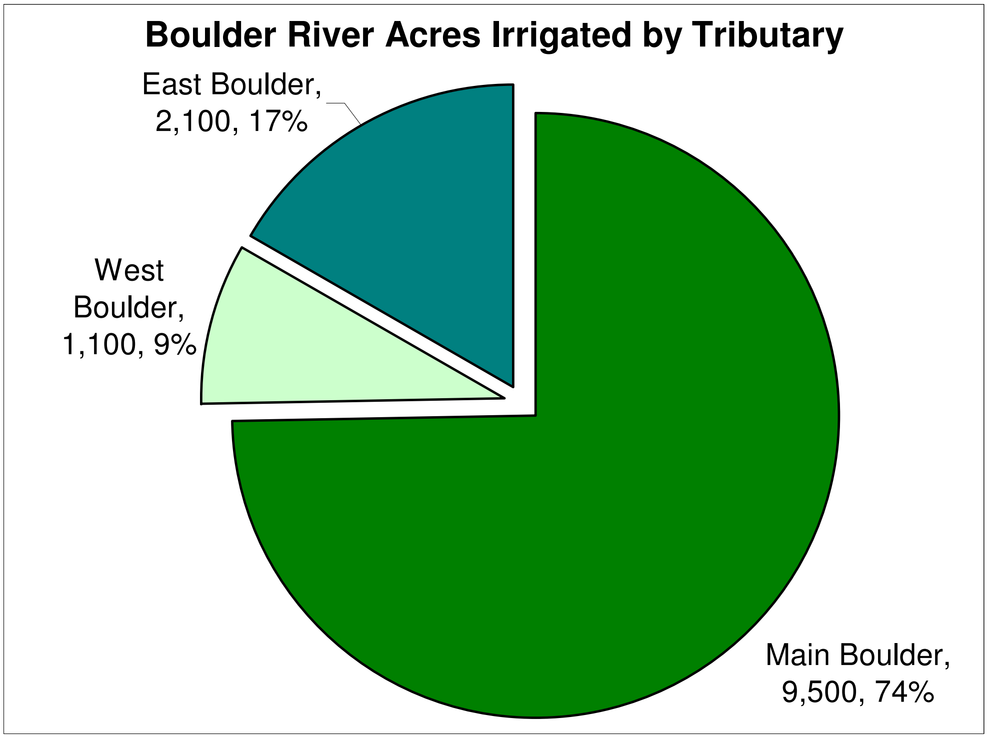
Maps 2 and 3 depict land irrigated with water from the Boulder River and tributaries to it.


Map 2.
Lower Boulder River Irrigation
Yellowstone River
Big Timber
Irrigated Land
Ditches
Watershed Boundary
N
0 1 2 3 4 5 Miles
Boulder River


Map 3.
Upper Boulder Watershed Irrigation
Boulder River
0 1 2 3 4 5 Miles
McLeod
Irrigated Land
Ditches
Watershed Boundary
N
West Boulder River
Boulder River
East Boulder River
Elk Creek

As depicted in Figure 1, most irrigated lands are supplied with water from the main Boulder River, but the East and West Boulder Rivers also supply water to a substantial amount of irrigated land. More land is irrigated with water from the East Boulder River than is irrigated with water from the West Boulder River: about 17 percent of the total for the East Boulder versus 9 percent of the total for the West Boulder.

Figure 1. Irrigated acres summary by source



Interestingly, it was found that much of the irrigated acreage in the watershed had not changed appreciably since the time of the Water Resources Survey. There currently are about 12,700 acres of land irrigated with water from the Boulder River and its tributaries. This is slightly less irrigated land than was mapped in the Water Resources Survey of 1950 for Sweet Grass County when about 13,300 acres were found to be irrigated with Boulder River water. Changing land ownership and uses could account for some of the decrease. The number of acres irrigated with water from the West Boulder River is about the same as it was in 1950. About 20 percent more acres appear to be irrigated with water from the East Boulder River and Elk Creek than at the time of the survey. There has been about a 7 percent decrease in the amount of acres irrigated from the Boulder River proper.

About 40 percent of the land irrigated with water from the Boulder River watershed is within the Yellowstone River Valley, just to the east and west of Big Timber. The higher elevation of the upper Boulder River, relative to the Yellowstone Valley, allows for the advantageous gravity delivery of water to these lands. Although topographically outside of the Watershed, these lands are included

in the irrigation inventory because the water supply is the Boulder River.

The acres irrigated by system type are described in Figure 2. Flooding (photo 2) is still the most common way of irrigating in the watershed. However, more and more flood systems are being converted from open field ditches to gated pipe (photo 3), and sprinkler irrigation systems are becoming more common (photo 4). During the four field seasons of this study a number of new center-pivot sprinkler systems and gated pipe systems were installed.

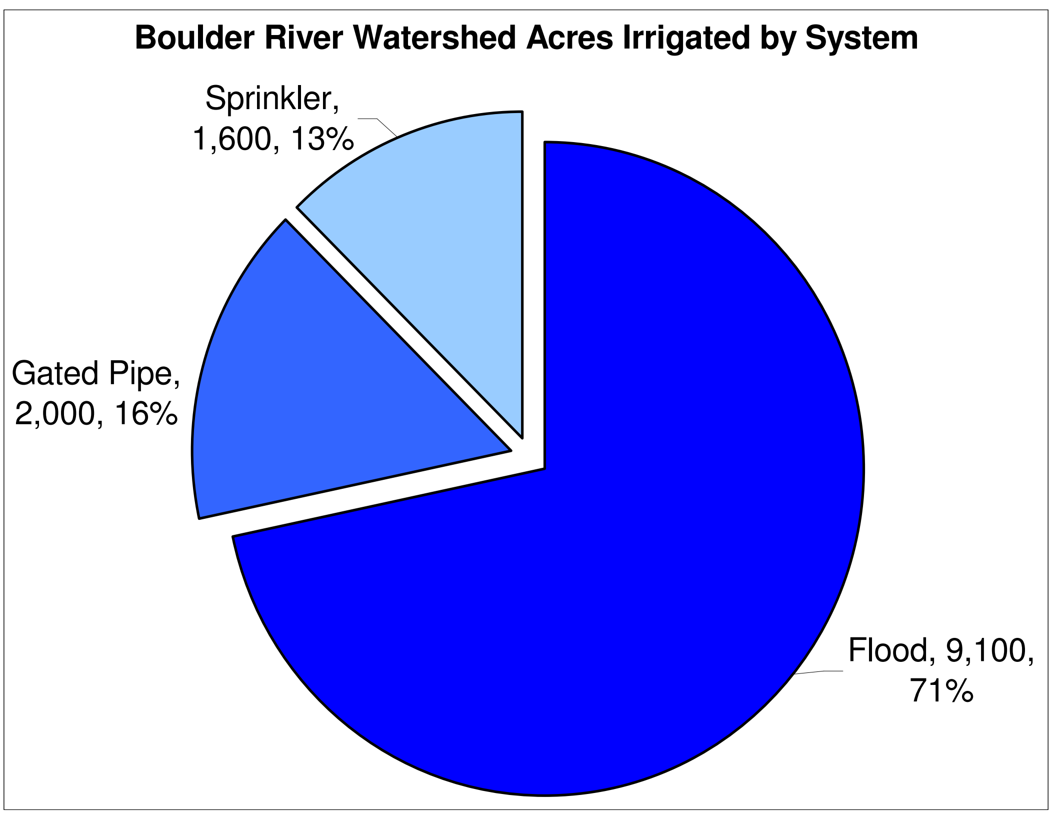
Photo 2. Flood Irrigation.

Photo 3. Gated pipe flood irrigation

Photo 4. Wheel Line Sprinkler Irrigation System

Appendix A contains more detailed maps of the irrigation in the watershed and these maps also identify the various ditches. Table A-1 (Appendix A) lists major irrigation ditches in the watershed and identifies the approximate number of acres presently irrigated by each ditch. Please note that the amount of acres irrigated by a ditch can vary from season-to-season and that the table may not be representative of the claimed irrigated acres for water rights purposes.

Figure 2. Irrigation by system type (2005)



Water Supply

During the 2003-2006 irrigation seasons, DNRC and the Association monitored streamflows in the Boulder River watershed to: (1) assess the available water supply for irrigation, (2) estimate amounts of water being diverted and consumed for irrigation, and (3) to determine how irrigation affects streamflows. Streamflow monitoring began when DNRC installed six streamflow gaging stations during May of 2003 (Map 4). Two gages apiece were installed on the East and West Boulder Rivers, which included an upper gage and lower gage on each river. The upper gages were installed where the rivers leave the mountains, above all irrigation diversions, in order to measure the inflows of these tributaries that are available for irrigation (photos 5). The lower gages were installed near the mouths of East and West Boulder Rivers to measure the amount of water leaving these tributaries and entering the Boulder River. The DNRC gages were equipped with capacitance-type water level loggers. To determine inflows from higher elevations to the Boulder River proper, DNRC reactivated a discontinued U.S. Geological Survey (USGS) stream gage on the Beaver Meadows ranch just below the Natural Bridge (photo 6).

Photo 5. Upper West Boulder River gage.

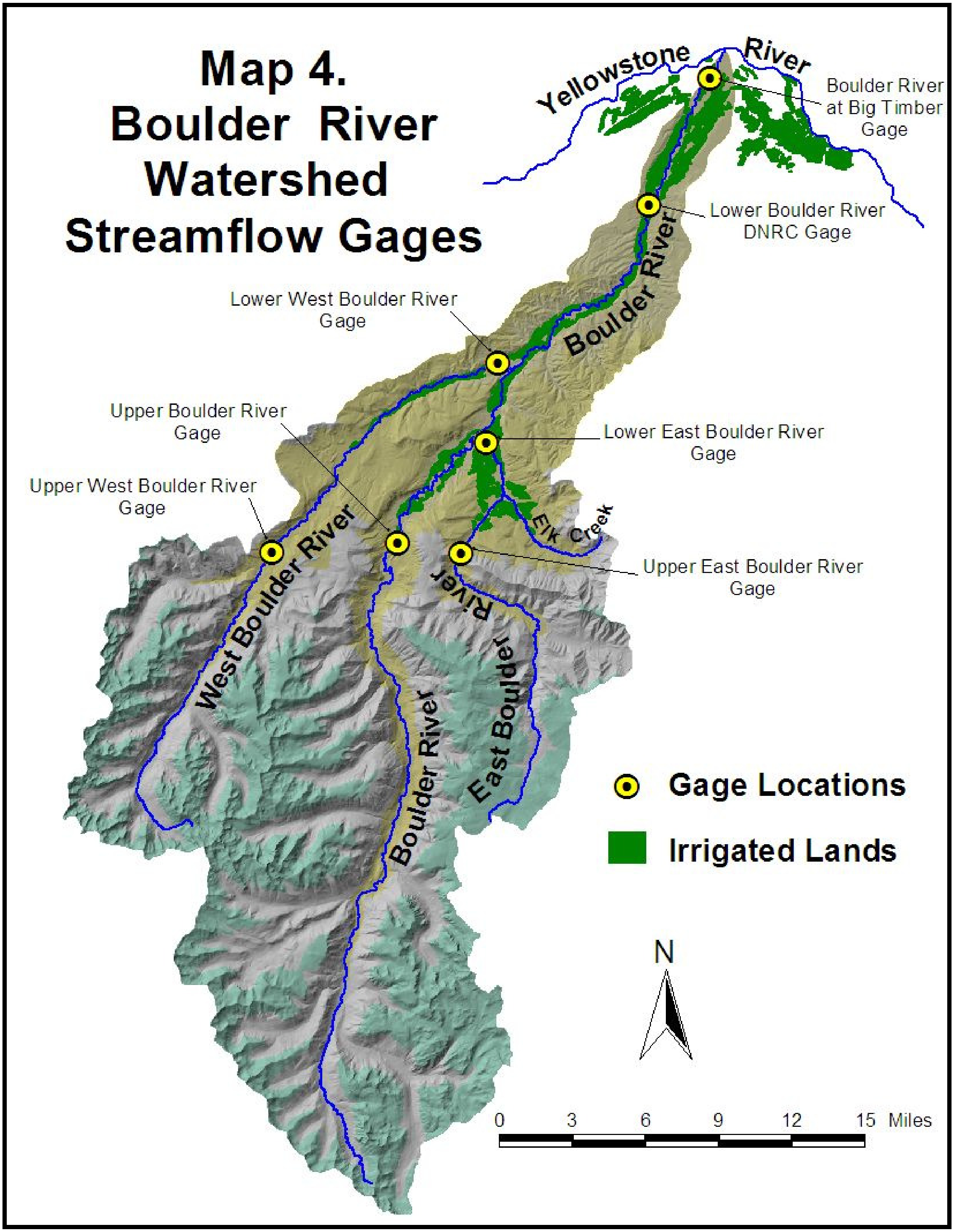

Map 4.
Boulder River
Watershed
Streamflow Gages
Yellowstone
River
Boulder River
at Big Timber
Gage
Lower Boulder River
DNRC Gage
Lower West Boulder River
Gage
Boulder River
Upper Boulder River
Gage
Lower East Boulder River
Gage
Upper West Boulder River
Gage
Elk Creek
Upper East Boulder River
Gage
West Boulder River
River
East Boulder
Boulder River
Gage Locations
Irrigated Lands
N
0
3
6
9
12
15
Miles

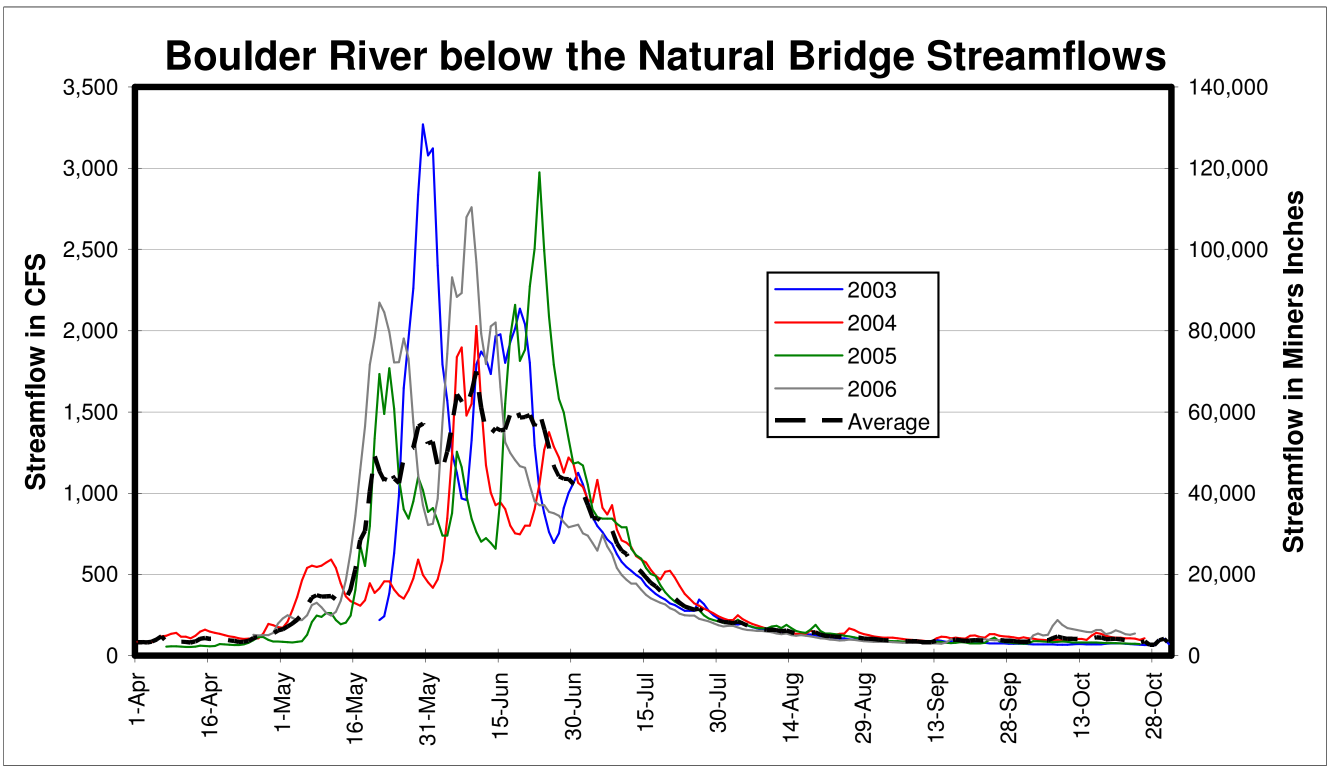
Photo 6. Upper Boulder River below the Natural Bridge gage.

Data from the active USGS gaging station on the Boulder River near Big Timber were used to determine the flow of the Boulder River where the watershed ends at Big Timber, near the confluence with the Yellowstone River. Because there are several large ditches that divert substantial amounts of flow from the lower-most Boulder River, DNRC installed another gage on the Boulder River about 5 miles upstream of Big Timber (photo 7). Streamflow data from this gage were compared to the lowermost USGS gage data to estimate irrigation diversions from the lower river by the larger ditches. Locations of the stream gaging stations are depicted in Map 4, with the irrigated land in the watershed also included to show where irrigation occurs relative to the gages.

Photo 7. Lower Boulder River DNRC gage.

Most Boulder River, and East and West Boulder streamflow originates from snow and rain that falls on higher elevation areas of the watershed. Streamflows peak during late May to mid June due to melting of the mountain snow pack and flow added by spring rains (Figure 3). The flow of the lower Boulder River generally peaked at about 3,000 cubic feet per second (CFS). Following this peak, streamflows quickly dropped during July as the snowpack was depleted. By August, streams were running at close to base flow. Once base-flow levels were reached, they were relatively consistent throughout the late summer, fall and winter; although flows usually increased some during the fall following the end of the irrigation season and the first fall frosts, and due to fall precipitation. During the late summer and winter, the flow in the lower Boulder River can be as low as about 100 CFS.

Figure 3. Streamflows for the Boulder River below the Natural Bridge

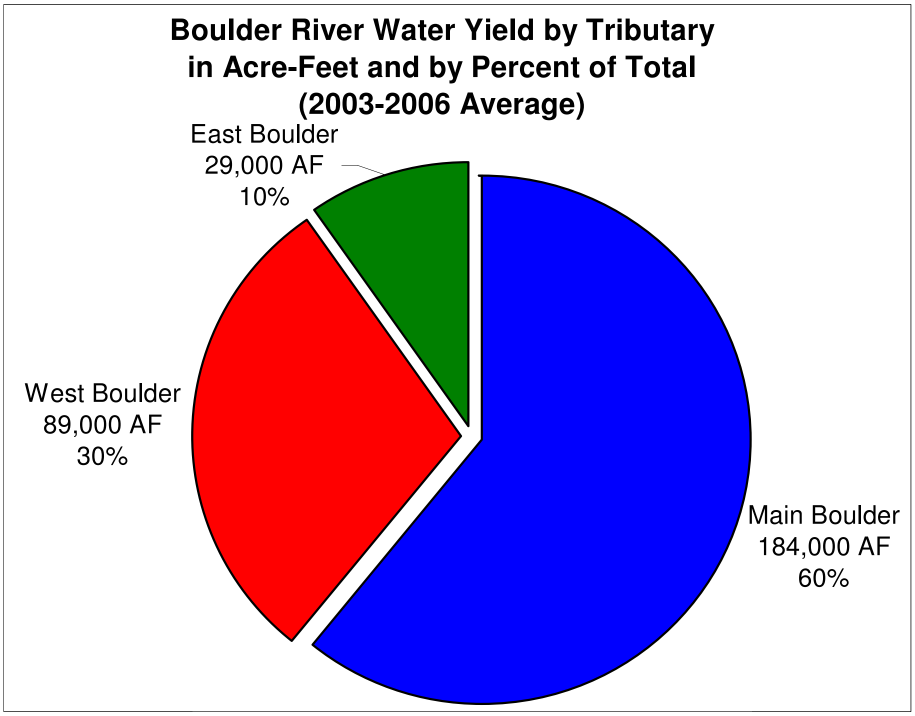


The majority of Boulder River flow comes from the main Boulder River upstream of the Natural Bridge, but the East and West Boulder Rivers are also substantial contributors as depicted in Figure 4. The West Boulder contributes about 3 times as much water as the East Boulder River. Flow data for the DNRC gaging stations and graphs of the flows at all the gaging stations for all years of the study are presented in Appendix B.

Elk Creek, although it was not gaged, contributes water to the East Boulder River. And Elk Creek water, if it were not consumed by irrigation, would have been captured as a portion of the flow at the Lower East Boulder River gage. On July 7, 2004, Elk Creek was measured as flowing 2.7 CFS near where it leaves the National

Forest, and 0.8 CFS where it enters the East Boulder River. On this same day the flow of the upper East Boulder River was measured at 70.2 CFS. Hence, the flow contributed by upper Elk Creek on that day was about 4 percent of the total flow produced in the East Boulder River watershed. Based on this, the inflow computations for the East Boulder River watershed were increased by 4 percent to roughly account for the added inflows from Elk Creek.

Figure 4. Average April through October total water volumes in acre-feet for the Boulder River Watershed.



To identify whether or not the rivers were naturally gaining or losing water between the gaging stations, early spring and fall flow data were examined. The early spring data are probably the best to use because this is when flows are generally lowest and after most irrigation return flow from the previous summer has reached the stream. Small flow gains and losses between the gaging stations are identified and described in the paragraphs that follow. Because these gains and losses usually were minor, they generally were not factored into the overall analyses.

There was only a small difference between flows at the upper West Boulder and lower West Boulder gaging stations during early April, when the gages usually were started. Sometimes the flow at the upper gage was slightly higher than the flow at the lower gage; at other times the flow was slightly lower. But on average flows at the lower West Boulder gage during April were about 2.5 CFS higher than those at the upper gage. This could be attributed to inflows from Grouse Creek and inflows from a few springs that are located along the

river between the two gages. During the fall, the lower portion of the West Boulder River usually gained about 2-to-10 CFS. This increase was likely due to the above mentioned inflows, irrigation return flows, and contributions from fall precipitation.

Prior to the irrigation season in April, flows in the lower East Boulder River usually were about 1-to-2 CFS lower than those at the upper gage. October flows generally were 1-to-10 CFS less at the lower gage. Lower springtime flows at the lower East Boulder gage could be attributed to stock water diversions or some channel seepage losses; lower fall flow could be attributed to these same losses, plus minor fall irrigation and stock-water diversions.

Flows at the DNRC lower Boulder River gage were similar to the early April combined flows of the Upper Boulder River, Lower East Boulder River, and Lower West Boulder gages; although there may have been natural gains of a few CFS to base flows in this segment of the Boulder River. During the fall, this section of river was gaining flow due to irrigation returns, as discussed later in this report.

In early April, flows were generally a few CFS higher at the Lower USGS Boulder River gage (at Big Timber) than at the DNRC gage about 5 miles upstream. During the later part of April, the reverse was true: flows generally were slightly higher at the DNRC station. The lower flows at the Big Timber gage during late April probably were due to some initial irrigation or stockwater diversions. Early fall flows generally were higher at the upper gage than at the lower due to late-season irrigation diversions. By the end of October, this difference usually was less than 10 CFS.

Irrigation Water Use

East Boulder River Drainage

In Figure 5, East Boulder River inflows, as measured at the upper gaging station, are compared to East Boulder outflows at the lower gaging station. The space in the graph between the inflow and outflow lines can be used to approximate the amount of water that has been removed for irrigation. This removed water would include: (1) evapotranspiration of water (water transpired through the leaves of the plants plus that evaporated from the soil and plant surface) by irrigated crops on fields entirely within the East Boulder River watershed, and (2) water that was diverted, minus some initial canal loss, for lands that were irrigated with East Boulder River water but located adjacent to the main Boulder River. During much of the irrigation season, the flow at the lower gage was about 30-to-50 CFS lower than that at the upper gage. By late summer and during September, the amount of water used by irrigation was limited by the inflows rather than by the irrigation demand, to about 20-to-30 CFS. East Boulder River flows are compared as average monthly accumulated volumes in acre-feet in Table 1.

Figure 5. East Boulder River Average Inflows and outflows for the 2003-2006 seasons.

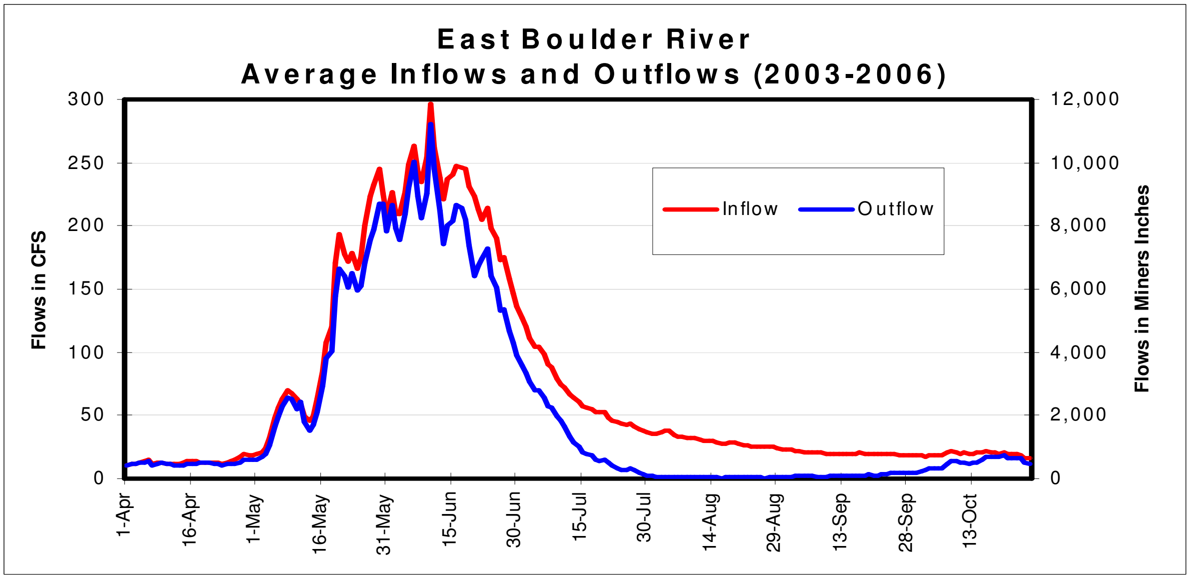


Table 1. Average Inflows versus outflows for East Boulder River (2003-2006)

Month	Inflow (acre-feet)	Outflow (acre-feet)	Difference (acre-feet)
May	8,400	6,300	2,100
June	13,600	11,300	2,300
July	4,200	1,900	2,300
August	1,900	50	1,850
September	1,200	200	1,000
Total	29,300	19,750	9,550

Note: Gaged East Boulder inflows were increased by 4 percent to account for ungaged inflows from Elk Creek; May 2005 data were not used to compute May averages because substantial unaccounted for low elevation inflows were occurring then.

The total seasonal volume of water removed from the East Boulder River drainage for irrigation averaged about 9,550 acre feet. For the approximately 2,100 acres irrigated, this amounts to about 4.5 acre-feet per acre irrigated.

Some of the water that is diverted from the East Boulder River into the Miles-Decker, Boe-Engle, Smoot, and DeHart ditches, is used to irrigate land that is adjacent to the Boulder River proper (see Map A-1 in Appendix A). Hence, return flows from about 750 acres of the land irrigated with East Boulder River water would go to the main Boulder River, or to the East Boulder River below the lower gage. Also, the differences between East-Boulder watershed inflows and outflows during late July, August and September do not reflect the entire potential demand on the stream, because diversions would have been higher had more streamflow been available.

West Boulder River Drainage

Figure 6 and Table 2 compare average basin inflows and outflows for the West Boulder River. The space between the inflow and outflow lines can be used to estimate flow reductions due to irrigation, and these reductions generally were in the 20-to-40 CFS range. As with the East Boulder River, some of the water diverted from the West Boulder River is used to irrigate land adjacent to the Boulder River proper--both to the north and south of where the West Boulder River joins the Boulder River (see Map A-2 in Appendix A). Inflows, outflows, and the differences between the two are presented in Table 2 as monthly accumulated volumes.

Figure 6. West Boulder River Average Inflows and Outflows for the 2003-2006 seasons.

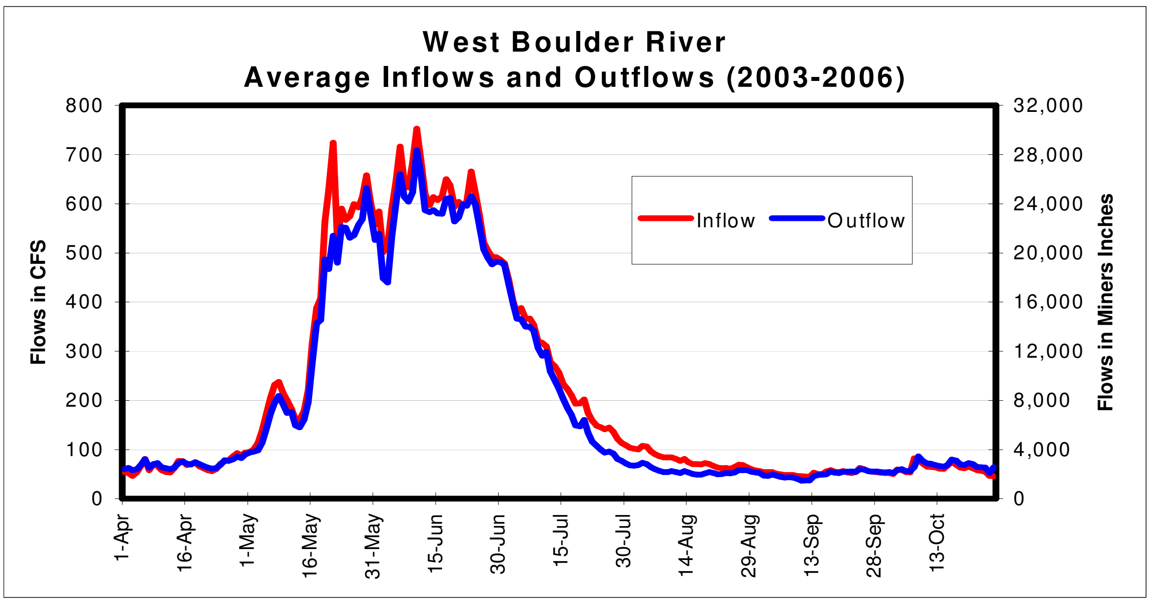


Table 2. Inflows versus outflows for the West Boulder River

Month	Inflow (acre-feet)	Outflow (acre-feet)	Difference (acre-feet)
May	20,900	19,200	1,700
June	35,800	33,900	1,900
July	15,200	13,400	1,800
August	4,700	3,500	1,200
September	3,100	2,900	200
Total	79,700	72,900	6,800

Note: Flow data for 3 days during May were not used in these computations because water levels were higher than what the lower West Boulder gage could measure, and because the stage-discharge rating was not accurate for flows above about 900 CFS.

The total seasonal volume of water removed from the West Boulder River drainage for irrigation averaged about 6,800 acre-feet. For the approximately 1,100 acres of land irrigated, this amounted to about 6 acre-feet per acre. This 6,800 acre-feet would have gone to: (1) water consumed by evapotranspiration for irrigation that is within the West Boulder River drainages, and (2) diversions (minus some canal losses) for lands in the Boulder River valley proper that are supplied with water from the West Boulder River. Return flows from about 680 acres of the land irrigated with West Boulder River water go to the main Boulder River.

Unlike the East Boulder River, water was available in the West Boulder River throughout the irrigation season. However, because the river channel contains many large boulders and is steep, some irrigators have difficulty backing water up in the stream and diverting it down their headgates late in the season when water levels are low. By the end of summer streamflows at the upper and lower West Boulder River gaging stations were similar, possibly because irrigation diversions were balanced out by lagged ground water return flows from flood irrigation earlier in the season.

Upper Boulder River Watershed

Figure 7 depicts total inflows and outflows from the Upper Boulder River watershed, which encompasses the entire watershed upstream of the DNRC gage about 5 miles above Big Timber, including the East and West Boulder drainages. Watershed inflows on the graph are a summation of the streamflows at the following gaging stations: (1) the Boulder River below the Natural Bridge, (2) the upper East Boulder River, and (3) the upper West Boulder River. Watershed outflows are the flows measured at the DNRC lower Boulder River gage. The graph contains values only for the late summer (from mid-July on). The gage usually was not operated during the mid-May to Mid-July runoff period, because the gage was either submerged or water levels were higher than the instrument could measure. Also, because there was no bridge at the site from which higher discharge measurements could be made, flow estimates at this site are only accurate up to about 900 CFS: the highest flow at which the river could be waded across. As with the other graphs, the space between the inflow and outflow lines can be used to estimate flow reductions due to irrigation. The inflows, outflows, and flow reductions for the mid-to-late summer period are summarized as volumes in Table 3.

Figure 7. Upper Boulder River Watershed Inflow/Outflow Comparison.

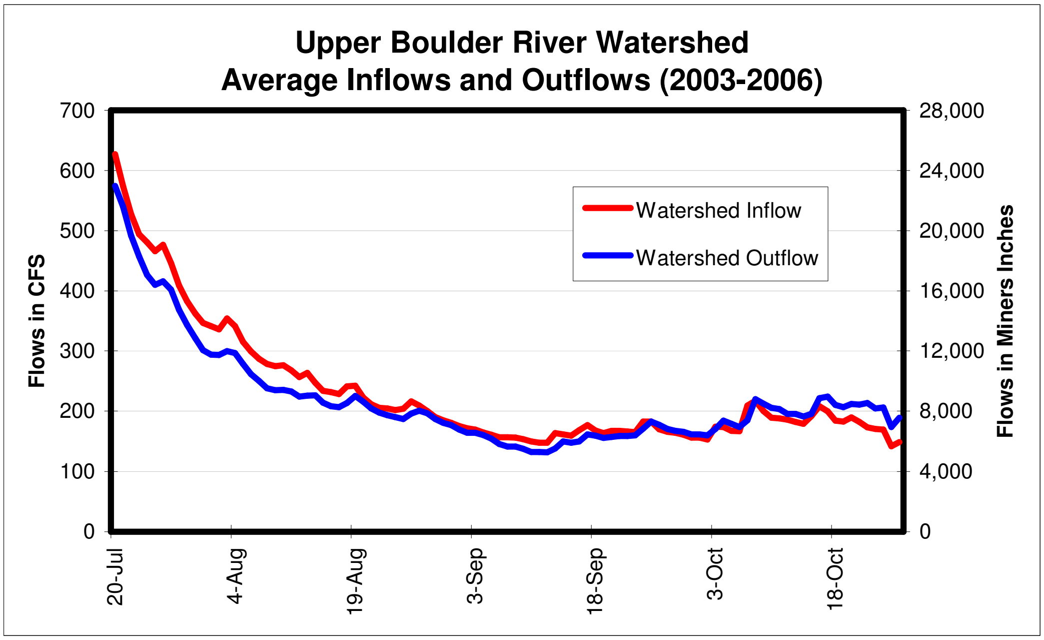


Table 3. Inflows versus outflows for the Upper Boulder Watershed

Month	Inflow (acre-feet)	Outflow (acre-feet)	Difference (acre-feet)
July 15-31	18,000	16,500	1,500
August	15,400	13,900	1,500
September	9,800	9,300	500
Total	43,200	39,700	3,500

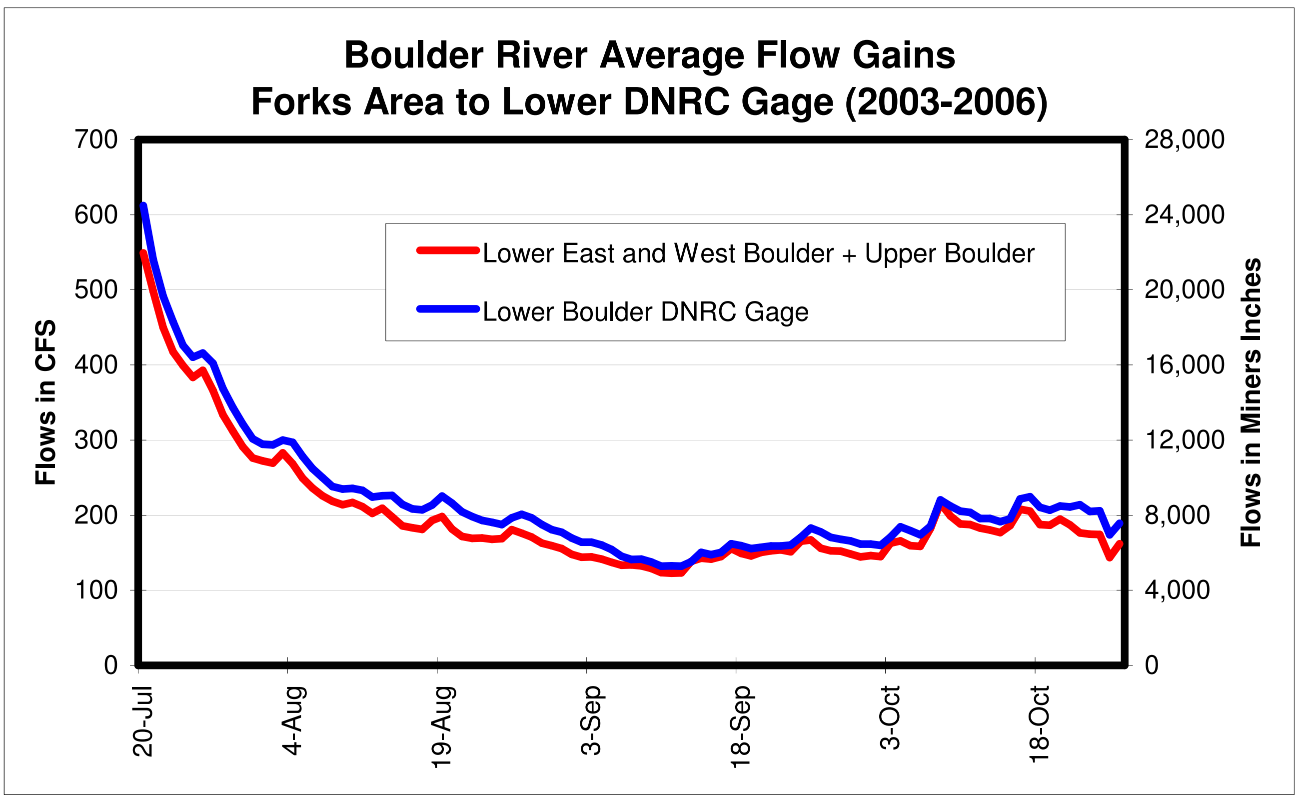
The difference in volume of 3,500 acre-feet between inflows and outflows can be attributed mostly to the evapotranspiration of water by crops on the approximately 6,500 acres of land irrigated in the upper watershed (although there are some return flows from irrigation by the Ellison, Clause-Weaver, and Lamp-Nelson Ditches that likely enter the Boulder River below this station). The 3,500 acre-feet of water consumed is equivalent to a little more than one-half an acre-foot, per acre irrigated. Because water requirements for the July 15 through September period represent about one-half of the season total, seasonal evapotranspiration by crops in the upper watershed were approximated by doubling the one-half an acre-foot per acre amount to about 1.1 foot acre-foot per acre irrigated. Keep in mind that this is an estimate of the amount of water <u>depleted</u> in the upper watershed through evapotranspiration and not the total diverted, which would be much higher (perhaps about 6.5 acre-feet per acre as discussed later in the report).

There may be some inaccuracy in this depletion estimate due to groundwater return flows. During the later part of the summer, return flows from irrigation earlier in the season probably are adding some flow to the river. Figure 7 shows that, by late August, the inflow and outflow for the upper Boulder River watershed are relatively similar. This may be due to the effect of groundwater

returns from irrigation earlier in the season, which are offsetting, to some degree, water diversions.

Irrigation returns are most apparent in the middle sections of the Boulder River: from the Boulder River Forks near Mcleod, to the lower DNRC gage about 5 miles upstream of Big Timber. This segment of river was consistently gaining water during the summer. To illustrate this, Figure 8 compares estimated average flows for the Boulder River at the Forks near Mcleod (the summation of the lower East Boulder, lower West Boulder, and Boulder River below the Natural Bridge gages) to flows at the lower DNRC gage. During late summer, the river typically gained about 20 CFS in this segment. These gains probably are due to irrigation return flows entering this portion of the river, and particularly returns from ditch systems that originate in the East and West Boulder River watersheds and terminate in the Boulder Valley proper.

Figure 8. Middle Boulder River flow gains, Forks to 5 miles upstream of Big Timber.



Lower Boulder River

The lower Boulder River is the segment from the DNRC gage about 5 miles upstream of Big Timber, to the USGS gage at Big Timber. Figure 9 compares lower Boulder River flows during the later part of the

summer and fall; the space between the lines primarily represents flow reductions due to irrigation withdrawals. Lower Boulder river flow reductions during July and August generally were from about 100 to 150 CFS. Table 4 summarizes inflows, outflows, and reductions by monthly volumes. May estimates also are included in the table but these are less accurate than those for the other months, because the gage was not operated during May in the first year of the study and because it was operated for only portions of May in 2005 and 2006.

Figure 9. Lower Boulder River Inflows and Outflows.

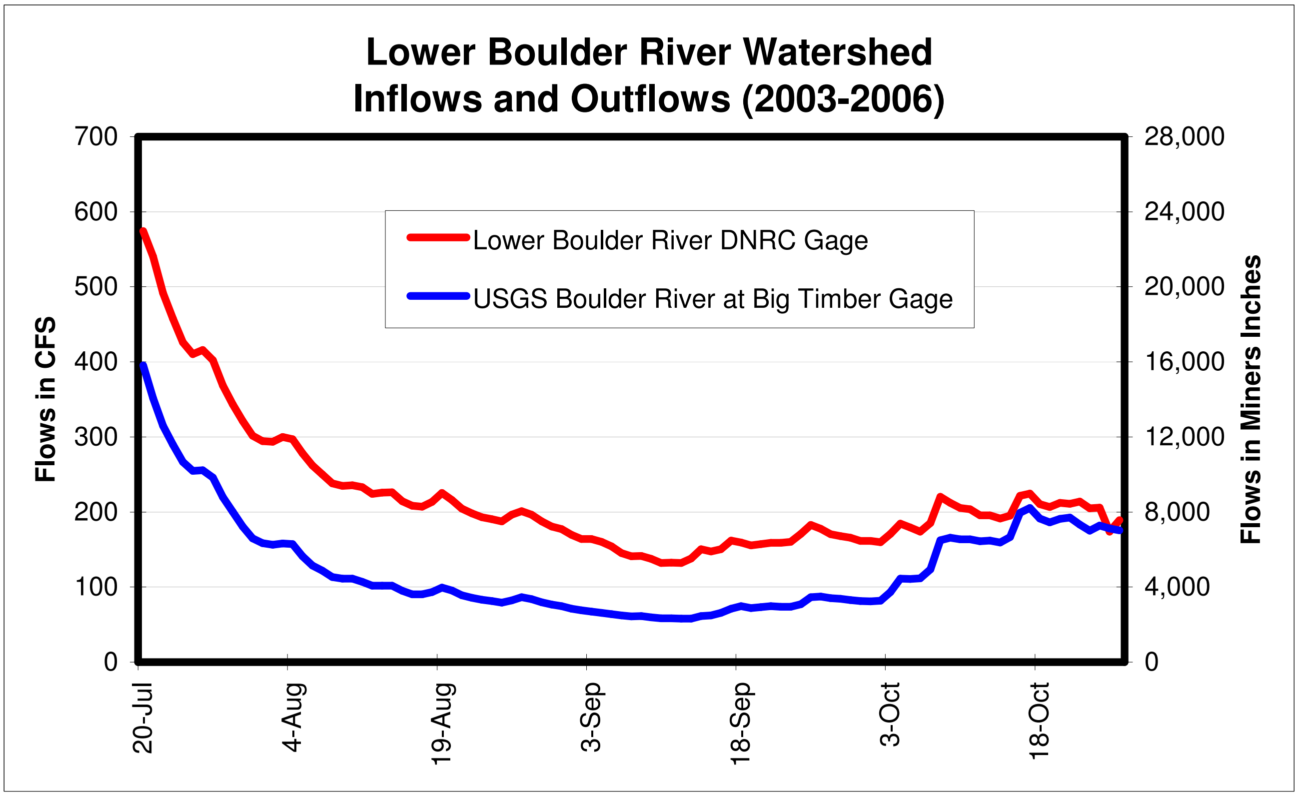


Table 4. Inflows versus outflows for the lower Boulder River

Month	Inflow (acre-feet)	Outflow (acre-feet)	Difference (acre-feet)
May	66,200	58,400	7,800
July 15-31	16,500	11,000	5,500
August	13,900	6,400	7,500
September	9,300	4,200	5,100
Total	105,900	80,000	25,900

Note: May flow estimates are based on only the 2004 data, and a portion of the month for 2005 and 2006.

Several major ditches divert water from the Boulder River between these two gaging stations, and these ditches provide irrigation water to about 6,300 acres of land. About three-quarters of this land is located topographically in the Yellowstone River Valley, to the west and east of Big Timber. Because most return flows from irrigation supplied by the lower ditches enter the Yellowstone River and not the Boulder River, flow reductions in the lower river are

the summation of: (1) total diversions for the irrigation of land to the west and east of Big Timber, minus some returns from canal seepage that would occur in the Boulder Valley, and (2) evapotranspiration use by crops on the irrigated land in the Boulder Valley between the DNRC gage and Big Timber. For the May and late-summer periods, Table 4 indicates that flow volume was reduced by about 25,900 acre-feet, or about 4 acre-feet per acre irrigated. Because the month of May and the period between July 15 through September 30 encompass about two-thirds of the irrigation season, total seasonal flow reductions from the lower river might be about 50 percent higher, or 6 acre-feet per acre.

There are other water uses in the lower Boulder Watershed. The source of water for the City of Big Timber is an infiltration gallery below the bed of the Boulder River, just downstream of the site of the lower Boulder River DNRC gage. DNRC contacted the City to get an idea of how much water was diverted through the infiltration gallery. Diversions by the City during the 2003 and 2004 irrigation seasons are summarized in Table 5.

Table 5. City of Big Timber Infiltration Gallery Diversions.

Month	Average Diversion Rate in CFS	
	2003	2004
April	.52	.46
May	.67	.79
June	.95	.96
July	1.8	1.4
August	1.4	1.3
September	1.4	1.0
October	.49	.44
Average in CFS	1.0	.91
Total volumes (acre-feet)	440	390

Entire Watershed

Figure 10 is an inflow-outflow graph for the entire Boulder River watershed. Inflows are the combined measured flows at the upper East Boulder River, upper West Boulder River and Upper Boulder River (below the Natural Bridge) gages; this approximates total inflows to the watershed from the higher elevations, prior to irrigation diversions. The outflow line is the average flow of the Boulder River at the USGS Boulder River at Big Timber gaging station. The space between the "Watershed Inflow" and "Watershed Outflow" lines is an indication the amount of water that is removed from the Boulder River watershed by (1) irrigation depletions within the watershed, and (2) diversions to irrigate land outside of the watershed. Basin inflows, outflows, and the differences between the two are summarized in Table 6.

Figure 10. Boulder River Watershed Average Inflows and Outflows for the 2003-2006 seasons.

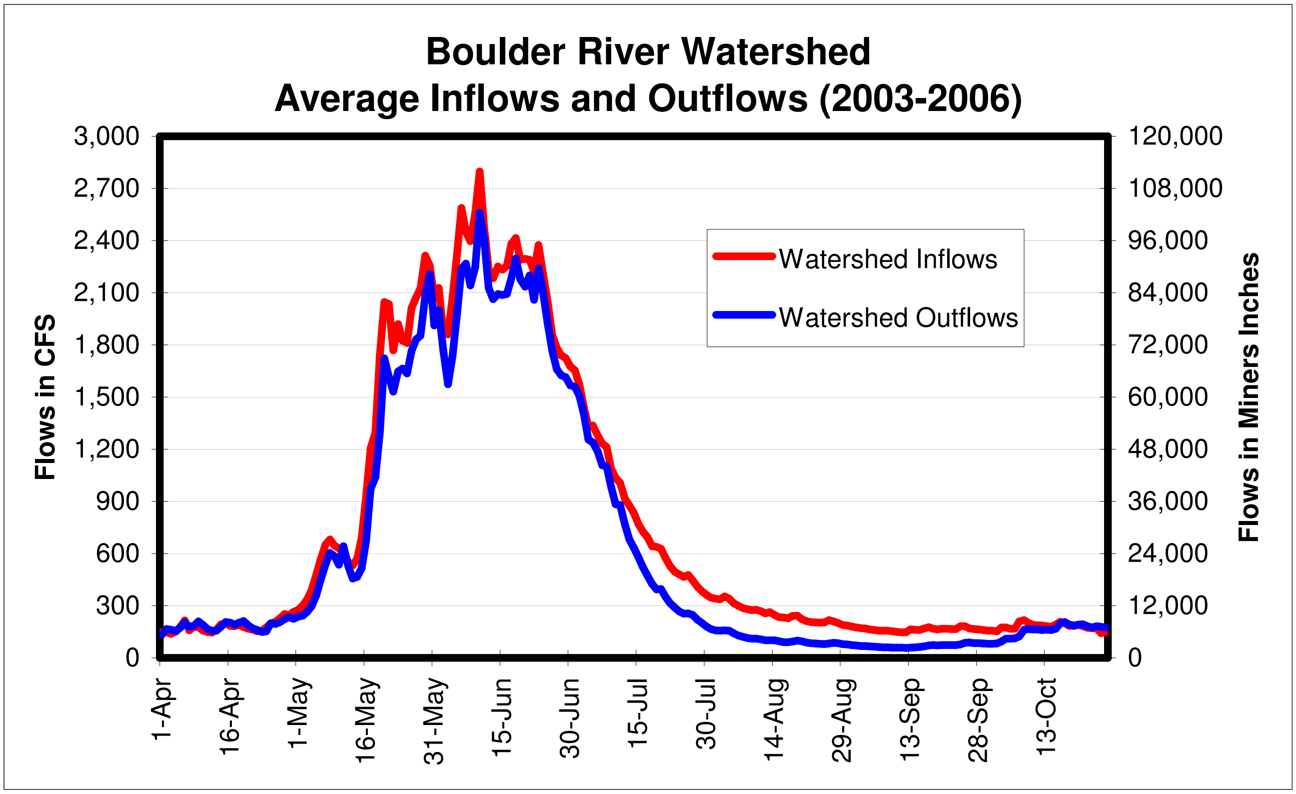


Table 6. Inflows versus outflows for entire Boulder River Watershed (2003-2006 data)

Month	Inflow (acre-feet)	Outflow (acre-feet)	Difference (acre-feet)
May	72,000	63,800	8,200
June	129,600	120,800	8,800
July	51,300	41,100	10,200
August	15,400	6,400	9,000
September	9,900	4,200	5,700
Total	278,200	236,300	41,900

Note: total depletions from mid-May to mid June were estimated for some days when using inflow/outflow data resulted in unreasonably high values.

The differences between inflows and outflows are primarily due to: (1) water consumed by evapotranspiration on approximately 7,500 acres of irrigated fields within the Boulder River watershed, and (2) total water diversions (minus some initial ditch seepage losses) for irrigated land that is topographically outside of the watershed to the east and west of Big Timber. Also included in the differences is some evaporation from the surface of the Boulder River, which is discussed in the section that follows. The average volume of water depleted from the watershed per season was estimated to be 41,900 acre-feet. Overall, this represents about 3.3 acre-feet of water per acre irrigated.

River Surface Evaporation

A portion of the water depleted from the Boulder River Watershed can be attributed to evaporation from the surface of the streams. Surface areas of the Boulder River and its major tributaries were digitized and acreages estimated using the Watershed GIS. Approximate surface areas, in acres, for the streams were as follows:

- Boulder River, Natural Bridge to Yellowstone confluence: 486
- West Boulder River, Upper gage to Boulder confluence: 137
- East Boulder River, Upper gage to Boulder confluence: 29
- Total: 652

An estimate of the seasonal evaporation from this water surface is about 1,600 acre-feet, or about 2.5 acre-feet per-acre of surface area. There is not much information available on evaporation rates from flowing water surfaces in Montana. The seasonal amount of about 2.5 acre-feet per acre is a rough estimate and it is based on the DNRC hydrologist's interpretation of a study on evaporation rates from the surface of Milk River in southern Alberta, Canada (Morton 1985). Surface area evaporation is a relatively small component of the water balance for the watershed: it amounts to less than 1 percent of the watershed inflow, and it is equivalent to about 4 percent of total flow reductions in the watershed.

Water Supply during the 2003-2006 seasons compared to other years

The 2003-2006 irrigation seasons were all drier than average from a water supply standpoint. The USGS gaging station at Big Timber has been operated continuously from 1955 through 2006. Table 6 is a statistical comparison of flow data for the study period versus the long-term record for the Boulder River at the USGS gaging station at Big Timber.

Table 7. Comparison of Boulder River at Big Timber flows during study to long-term recorded flows.

Study Years	May (CFS)	June (CFS)	July (CFS)	August (CFS)	September (CFS)	May – Sept. Volume (acre-feet)
2003	1,070	2,441	621	98.1	71.7	260,000
2004	492	1,592	806	115	83.5	187,000
2005	1,049	2,111	812	138	72	253,000
2006	1,313	1,979	434	66.5	52.8	232,000
2003-2006 Average	981	2,030	668	104	70.0	233,000
Long Term Record (1955-2006)						
Average	1,130	2,712	1,213	231	183	331,000
75th Percentile Exceedence	827	2,181	676	113	101	260,000

Source: U.S. Geological Survey streamflow data, http://waterdata.usgs.gov.

Flows during all months of the study, except during May of 2006, were below the long-term 1955-2006 monthly averages; total flow volumes during the irrigation season (May-September) were also below the long term average for all four years of the study. Flows during

the 2003-2006 seasons were all below the 75 percentile exceedence flows. This means that during about three-quarters of the years since 1955, irrigation season flows in the Boulder River were higher than those during the 2003-2006 study period. Also note that, over the long-term, July average flows are greater than May average flows, while the opposite was true during the study period. This suggests that, during the study period, runoff from the watershed was occurring earlier than is typical.

The low water supply during the study period probably was due to low precipitation in the higher elevations and low snow accumulation during the winter. Table 8 shows precipitation during the study period at Big Timber as compared to the long-term average, indicating that, although mountain precipitation may have been low, precipitation was generally near-average at this lower elevation site.

Table 8. Precipitation at Big Timber during study period compared to long-term averages.

Year	Precipitation in Inches												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2003	1.41	1.42	1.53	2.32	2.16	3.39	0.62	0.41	0.39	1.31	0.33	1.34	16.63
2004	0.18	0.72	0.15	1.55	1.51	2.17	1.64	0.67	0.55	3.3	0.24	0.26	12.94
2005	0.46	0.05	0.94	2.76	4	2.97	1.33	1.08	1.56	0.99	1.18	0.38	17.7
2006	0.53	0.11	0.65	2.51	1.67	2.78	0.95	0.32	1.63	4.44	0.13	0.68	16.4
Average	0.65	0.58	0.82	2.29	2.34	2.83	1.14	0.62	1.03	2.51	0.47	0.67	15.92
1897-2006 Average	0.6	0.49	0.96	1.55	2.66	2.54	1.27	1.12	1.42	1.31	0.77	0.56	15.39

Source: Western Regional Climate Center, www.wrcc.dri.edu.

Ditch Efficiency Assessments

Some of the water diverted down irrigation ditches is lost to seepage or evaporation before it can be delivered to irrigated fields. DNRC and the Association estimated ditch losses and delivery efficiencies for a number of ditches. To estimate losses, ditch flows were measured at the river headgate, and then, subsequently, at stations further down the ditch (Photo 8). Where irrigation water was being taken out of a ditch, it was necessary to measure and account for the water being removed. All measurements were made by the Association's summer intern and the DNRC hydrologist. With all of this information, a water balance for the ditch was determined and seepage loss deduced. Map 5 depicts an example ditch loss analysis. Details on other ditch efficiency assessments can be found in Appendix C.

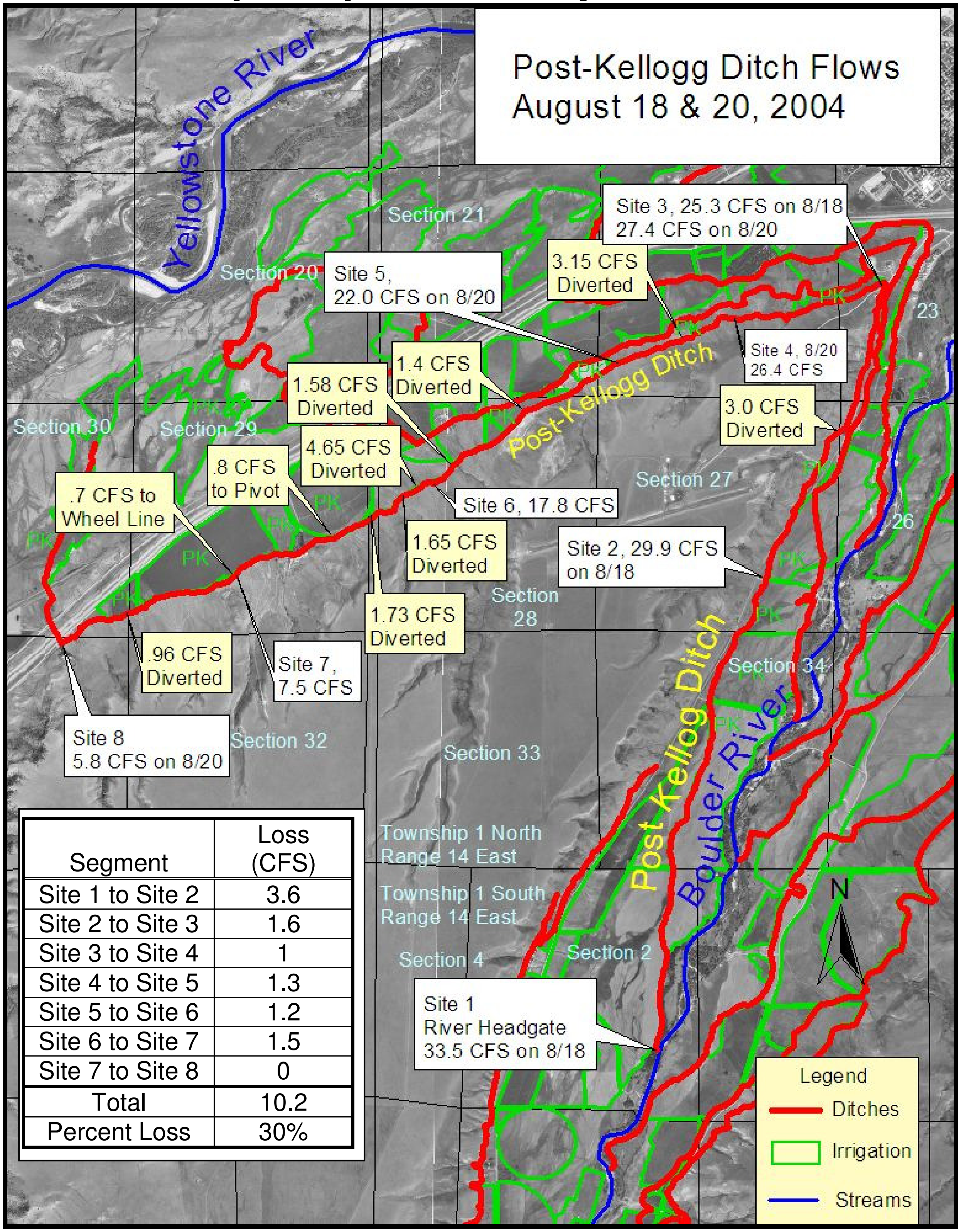
Photo 8. Measuring the flow of the McLeod Mutual Ditch

Ditches were measured using the same method as used for measuring streamflow: by extending a tape across the ditch and measuring the depth and velocity of the water at increments across the tape. The accuracy of these measurements generally is considered to be within about plus-or-minus 5 percent. For instance, if a ditch was measured as flowing 5 CFS (200 miners inches of water) then the actual flow might be anywhere from about 4.75 to 5.25 CFS (190 to 210 inches). In ditch segments where losses are relatively small, measurement error can mask actual losses, or lead one to deduce that a loss was occurring where there was none. Another potential source of error is when measuring and estimating diversions from a ditch. To reduce the potential for error, ditch seepage measurements were scheduled, when possible, at times when diversions from the ditch were minimal, such as during haying.

It also needs to be pointed out that ditch losses will vary with the amount of water that is flowing down the ditch; and losses may be higher earlier in the season than later in the season, or vice

versa. Given the numerous potential sources for inaccuracies, the stated ditch losses should be considered estimates and not absolutes.

Map 5. Example Ditch Efficiency Assessments.



Segment	Loss (CFS)
Site 1 to Site 2	3.6
Site 2 to Site 3	1.6
Site 3 to Site 4	1
Site 4 to Site 5	1.3
Site 5 to Site 6	1.2
Site 6 to Site 7	1.5
Site 7 to Site 8	0
Total	10.2
Percent Loss	30%

Measurements were made on 13 ditches, and the total length of ditch evaluated was about 45 miles. Cumulatively, these ditches provide water to about one-third of the irrigated land. Table 9 contains a summary of the ditch loss evaluations. Overall, ditch losses averaged about 28 percent, or a little over one-quarter of the total amount of water diverted. But as the table shows, there was much variability in ditch losses.

Table 9. Ditch loss measurement summary

Ditch	Water Source	Approx. Acres Irrigated	Length Measured (miles)	Initial Flow at Headgate (CFS)	Water Lost (CFS)	Percent Loss
Boe-Engle	East Boulder	700	3.6	15.5	2.2	14%
Clause-Weaver	Boulder River	86	2.3	3.4	1.3	38%
Conant-Dutton	Boulder River	171	1.5	14.8	0	0
Craft	East Boulder	338	2.4	10.7	6.8	64%
Electric Light	Boulder River	254	2.2	8.8	6.4	73%
Ellis-King-Hawks	Boulder River	721	6	22.5	9.0	40%
Elges	West Boulder	61	1.4	6.3	5	79%
Foster Rule	West Boulder	85	2.0	6.9	1.7	25%
Lamp-Nelson	Boulder River	439	4.6	23.8	3.0	13%
McLeod Mutual	Boulder River	510	5.9	15.3	3.3	22%
Miles-Decker	East Boulder	411	4.1	17	1.8	11%
Post-Kellog	Boulder River	663	7.6	33.5	10.2	30%
Tolhurst	East Boulder	106	1.4	6.5	1.3	20%
Totals		4,545	45	185	52	28% *

* Average loss based on total water lost divided by total flow for all headgate diversions; average of percentages for individual ditches is 33%.

For some ditches, more water was lost during conveyance than was ultimately delivered to the irrigated fields. Other ditches were found to be gaining water, at least in segments. There are a couple of explanations for why a ditch might be gaining water. First, wastewater from flood irrigation above the ditch could be running into the ditch and captured by it. Another possible explanation is that the water table in the vicinity of the ditch has been raised during the irrigation season and the ditch is functioning like a drain, capturing subsurface water that originates from irrigated fields or ditch seepage further up the slope.

Most measured ditch loss is due to seepage, but in some instances ditch flow exceeded capacity and water was spilling over the top of the ditch. Water also was observed to be leaking through field headgates that were not entirely sealed off, or flowing through rocky embankments. Water can also evaporate from the surface of a ditch. But, because the surface area of ditches is relatively small, these losses are minor.

Ditches generally are operated to ensure that sufficient water gets to the most distant irrigated lands on the ditch. Because setting the initial flow rate down the ditch is based on the operator's estimation of the water needs along the entire ditch, more water is

sometimes diverted down the ditch than is needed and the excess water has to be "wasted" off the end of the ditch by turning it into a stream or other channel. Also, the flow down many ditches is controlled, to some degree, by the flow of water in the river. That is, when the river level rises or drops, the flow of the ditch will rise or fall accordingly, even though the operator has not physically adjusted the headgate. This too can lead to over or under deliveries of water. Ditch efficiency estimates in this report do not account for any waste water that runs out at the end of the ditch. In this respect, overall losses are understated in this report.

The 28% average loss found in this study for the Boulder River is similar to an average loss of 32% (68% conveyance efficiency) found for earthen conveyance systems through a world-wide survey of irrigation water managers (IILRC 1992).

Canal Condition Assessments

While measuring ditch losses, the Association's student intern and DNRC staff walked the length of many of the ditches. While doing so, the conditions of the ditch and structures (such as headgates, crossings, flumes, and pump stations) were noted and assessed (Photos 9 and 10). These assessments were conducted for a number of the ditches. Copies of the assessments can be obtained from the Association.

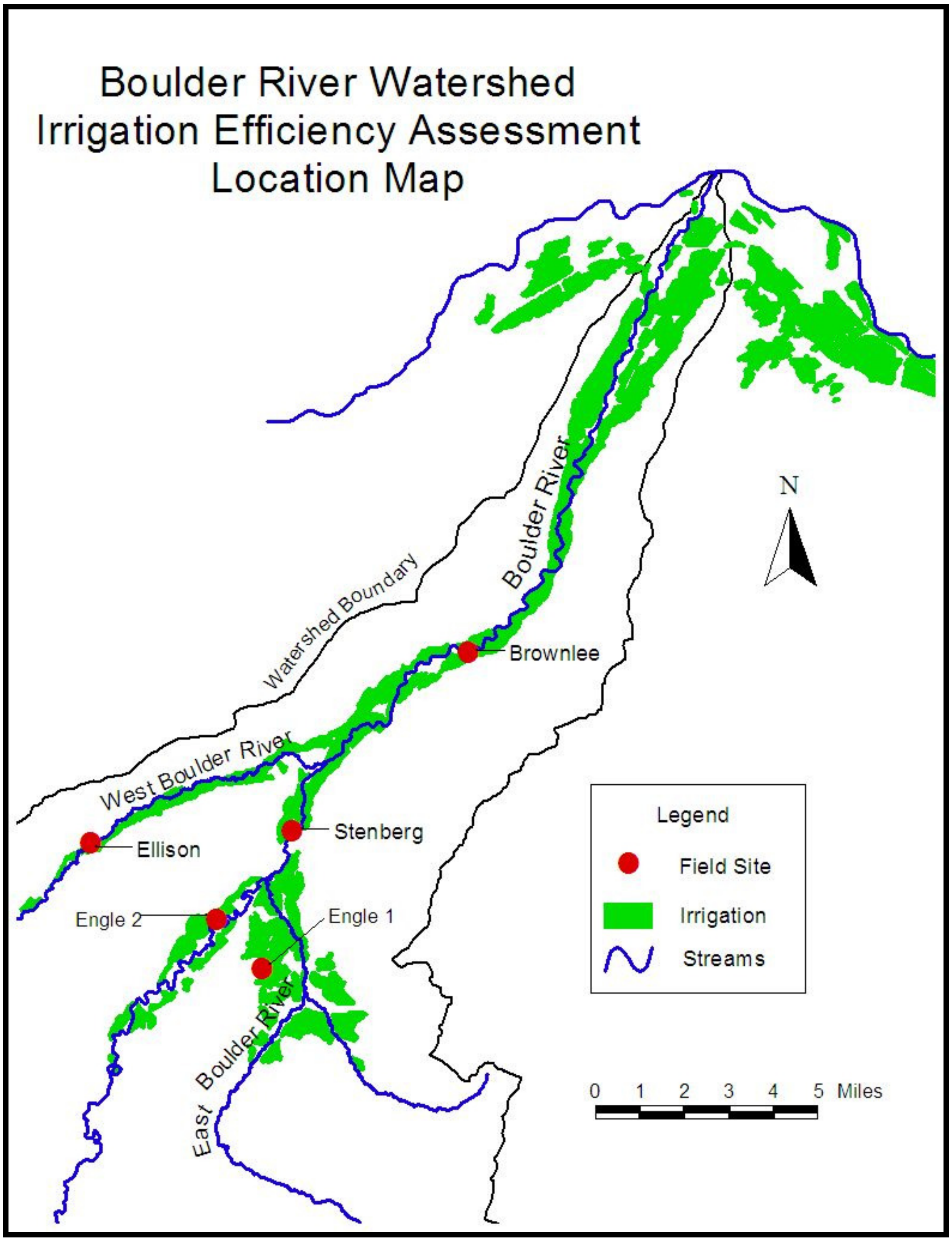
Photo 9. Canal Headgate on the Boulder River.

Photo 10. Damage to the Concrete on the Headgate.

Field Efficiency Assessments

DNRC and the Association investigated field efficiencies of irrigation in the watershed. The irrigation field efficiency is the percentage of the water which is applied to the field that is actually available for use by the crop. Because flood irrigation is the dominant type of irrigation in the Boulder River Watershed, flood irrigation systems were the focus of these investigations. Field efficiencies were evaluated on a sample of five flood-irrigated fields in the watershed (Map 6).

Map 6. Irrigation Efficiency Assessment Location Map



Field efficiency evaluations were planned and coordinated with the ranchers, so that they could be there to irrigate the field in a typical manner. Before the field was irrigated, the dimensions of the portion of the field that was to be irrigated or “set” was laid out, and a rough map of it drawn (Photo 11). Steel rings about 1-foot in diameter were driven into the set area at about 5 locations, so that infiltration rates could be measured at representative locations in the field once irrigation began. Several soil samples were taken within the set area to estimate available soil moisture prior to irrigation.

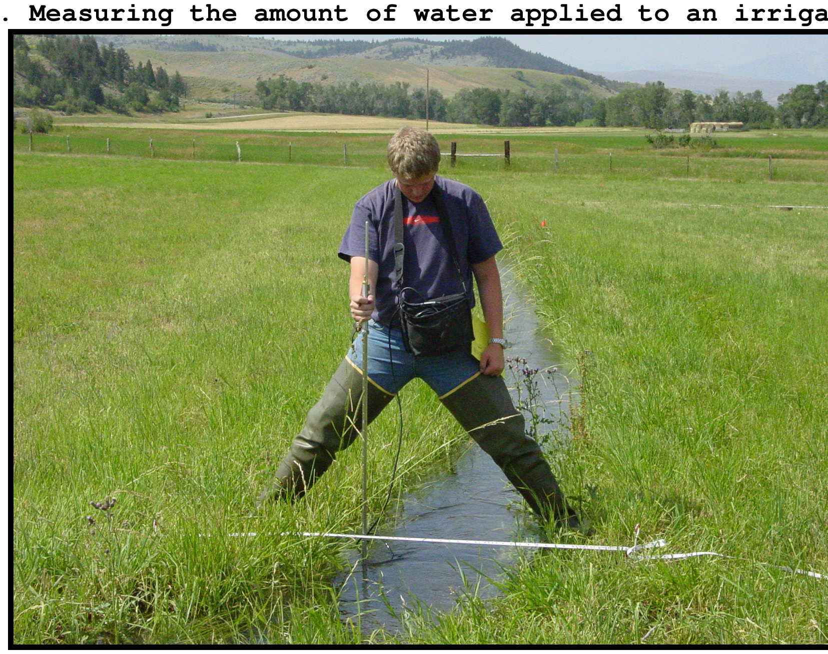
Photo 11. Laying out a field for an irrigation efficiency assessment

An auger was used to collect soil samples and soil moisture was estimated at various depths in the augured hole (Photo 12). The method used to estimate soil moisture was the feel and appearance method (USDA 1998). With this method, the soil sample is rolled and squeezing by hand to observe its texture and plasticity. Observed soil characteristics are then compared to those for a similar soil in the USDA Natural Resources Conservation Service (NRCS) manual, which contains photographs and descriptions of representative soils at various moisture levels. Once the field sample was matched with a photograph and description, the soil moisture level, as a percent of the available water capacity of that soil, was estimated using the manual. When using this method, the NRCS believes that an experienced observer can estimate soil moisture conditions within about 5 percent of actual.

Photo 12. Estimating soil moisture prior to irrigation

Once the set area was laid out and the soil moisture prior to irrigation was estimated, irrigation could begin. The rancher would flood the field either by damming the field ditch with tarps so water would spill onto the field or, in the case of gated pipe, by diverting water into the pipe and opening gates that are spaced along the length of the pipe. The time that irrigation started was noted and the rate at which water was being applied was estimated.

Photo 13. Measuring the amount of water applied to an irrigation set.



The amount of water being put onto the field was determined by measuring the flow of the supply ditch (Photo 13). In cases when the field was flooded with tarp dams, the flow of the ditch was measured just above the dams. When gated pipe was used, flows were measured in the ditch just above where it was funneled into the gated pipe.

If some water was getting around the dams or inlets to the gated pipe, this water was also measured, noted, and subtracted to determine the amount applied. Applied water generally was measured several times during irrigation and the rates averaged. The total volume of water applied was computed based on average flow rates and set duration.

Once water started to run across the field, the times it took to reach various points down the field were noted on the map of the set. When water reached an infiltration ring (Photo 14), water was poured into the ring with a bucket and the drop in water level in the ring was measured over time to estimate the rate of infiltration. Using the measured infiltration rate and duration of time that water was present at that location on the set, the amount of water that infiltrated into the soil at each location could be approximated.

Photo 14 Estimating soil infiltration.

Eventually, the irrigation water would reach the bottom of the set and start to run off the end of the field. This "tail water" was measured and accounted for (Photo 15). In some instances, tail water was captured by the next contour ditch in the field and it was easy to measure it using a small measuring flume or weir that was temporarily installed in the ditch. In a couple of cases tail water was more dispersed and had to be roughly estimated using a current meter, or by capturing it in a bucket where the water dropped off a bank and measuring the time it took for the bucket to fill with a stop watch. Tail water flow rates were measured several times, and the total volume of it computed based on measured rates and recorded times.

At the end of irrigation, the remaining water on the field was allowed to infiltrate or flow off before final soil moisture estimates were made. The method used to estimate soil moisture

following irrigation was the same as was used to measure pre-irrigation soil moisture, the feel and appearance method. Water added to the soil by irrigation is equal to the soil water following irrigation minus the soil water prior to irrigation. Soils generally were at 25 percent or less of capacity prior to irrigation and close to saturation following it; so irrigation was effective at bringing soil water levels to capacity. This generally amounted to about 4-to-6 inches of water added by irrigation to the first 2.5 to 3 feet of soil.

Photo 15. Measuring the tail water leaving a set.

In addition to the water that was held in the soil, some of the water that was applied during the set ran off as tail water; the rest most likely percolated through the soil and beyond the root zone. Much of this water eventually returns to a stream either directly, in the case of tail water, or through shallow aquifers. Determining the amount of water "lost" to deep percolation involved both estimation and actual measurement. The amount of deep percolation water was estimated as the remainder after the volume of water estimated to be stored in the soil and the volume of measured tail water leaving the field were subtracted from the initial volume of water applied to the field. Observed infiltration rates, from the infiltration ring data, were used as a check to determine if these deep percolation estimates were reasonable.

Table 10 contains a summary of the results of the field irrigation efficiency assessments. More details on each field assessment are contained in Appendix D.

Table 10. Field efficiency assessment summary.

Owner	Set Acres	System Type	Inches of Water Applied	Soil Water Deficit Prior to Irrigation (inches)	Tail-water surface runoff (inches)	Deep Percolation (inches)	Percent Efficiency
Engle 1	1.1	wild flood	7.8	3.3	2	2.5	42
Engle 2	.75	contour flood	23	4.1	2.9	16	18*
Stenberg	.30	gated pipe	21.7	4	5.1	12.7	18
Brownlee	.48	contour flood	29.4	4.3	5.7	19.4	15*
Ellison	.76	gated pipe	17	4	3	10	23*
Averages	.7		20	3.9	3.7	12.1	23

* Actual efficiencies for these systems probably are slightly higher because tail water from these fields is captured and reused.

Ranchers applied an average of about 20 inches of water to a set during an irrigation. Of the 20 inches applied, about 4 inches on average went to satisfy the soil water deficit and was available for crop use. A little less than 4 inches of water, on average, ran off the end of the field as tail water--although in some cases the ranchers indicated that they would capture this tail water and reuse it when flooding another set. It is estimated that 12 of the original 20 inches went to deep percolation.

Set sizes for these flood irrigation systems typically were relatively small: about an acre or less. However, the rate that water was applied to these small parcels was high: up to about 3 CFS. Set durations ranged from about 3 to 9 hours.

The duration of the set was based on the irrigator’s estimates of how fast water infiltrates into the soil and how long water must be allowed to flow to saturate the soil to capacity. The goal of irrigation is to flood the field until the soil moisture is raised to capacity. Because it often was mid-way through the set or longer before water reached the lower end of the field, water had the opportunity to infiltrate at the upper end of the field for a longer time than at the lower. So while the lower end of the field is just starting to soak with water, the soils at the upper end might already be filled to capacity. The result will be deep percolation of excess applied water at the upper end of the field and this is an inherent cause of inefficiencies in flood irrigation systems. Data from the infiltration ring measurements, and soil moisture analyses indicate that set times usually were sufficient to achieve irrigation goals.

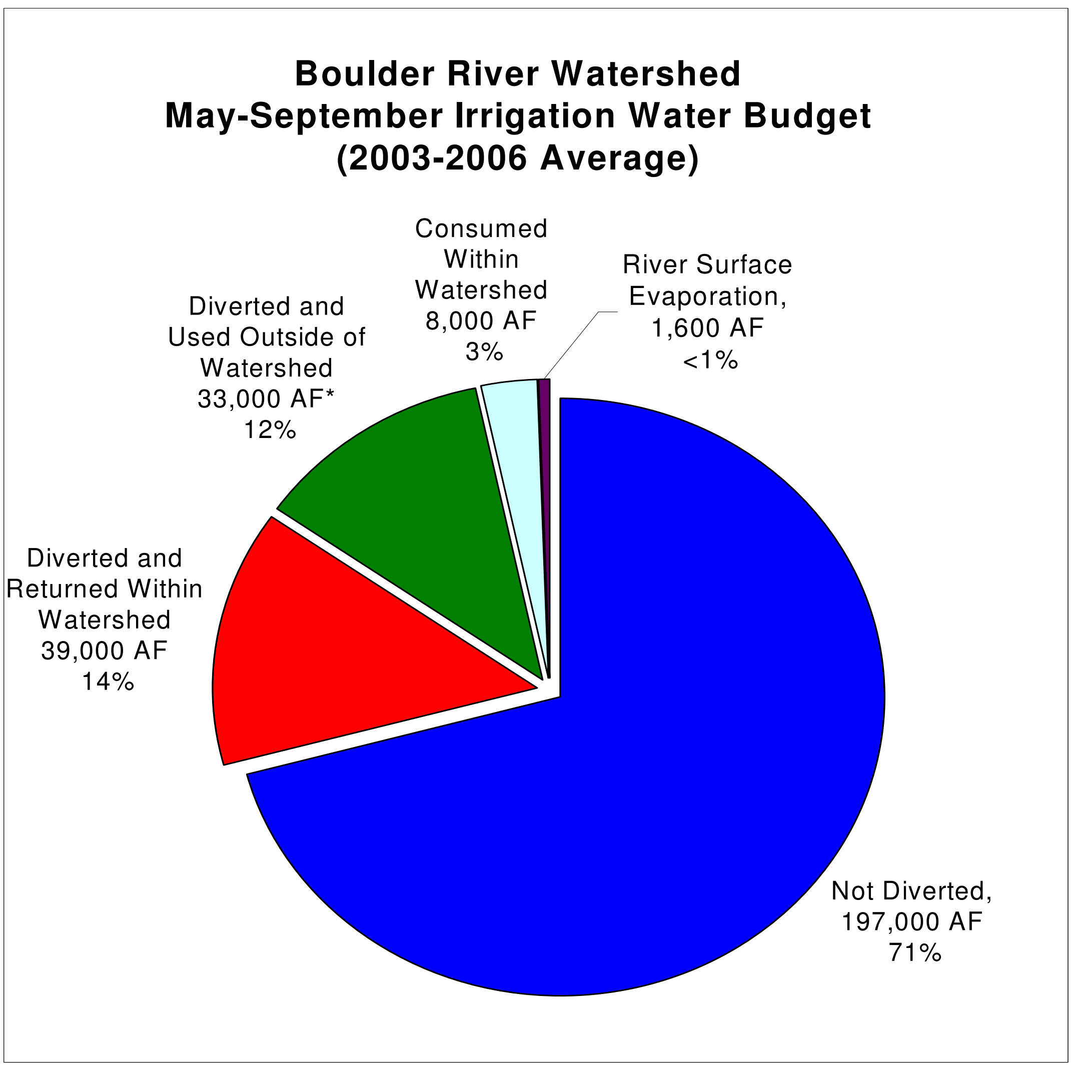
Soils at the field efficiency assessment sites were mostly loams, sandy loams, and clayey loams. Available water holding capacities in these soils are generally from about 1.5 to 2.0 inches per foot, or about 4.5 to 6 inches for the first 3 feet of soil. Although alfalfa can tap water from soil at greater depths, the crop on most fields that were assessed was a grass hay or an alfalfa-grass hay mix, so the soil moisture added to the first 3 feet was only accounted for in the efficiency assessments. Ranchers indicated that they generally irrigated each field 2 or 3 times over the course of a season. If from 4-to-5 inches of water is added to the soil per irrigation, these irrigation patterns might provide about 8-to-15 inches of moisture to the crop per season. Typical seasonal hay yields for flood irrigated fields were estimated to be from two-to-three tons per-acre. The Stenberg field did not have an established hay crop at the time of the assessment. Instead it had been planted that season with alfalfa and barley; the barley being a cover crop that protected the new growth of alfalfa as it was being established.

Discussion and Recommendations

Irrigation Water Use Efficiencies

The water used to produce hay or pasture is that which is transpired by the plant plus that evaporated from the soil and plant surface, which is referred collectively to as evapotranspiration (ET). On average, about 42,000 acre-feet less water flowed out the Boulder River each irrigation season at Big Timber than flowed into the river from the higher elevations (see Table 6). This water is estimated to have gone to the following: (1) about 8,000 acre-feet to crop consumption (ET) within the Boulder River watershed, (2) about 1,600 acre-feet to evaporation from the surfaces of the Boulder River, East Boulder River, and West Boulder River, and (3) about 33,000 acre-feet diverted to irrigate land topographically outside of the watershed (to the east and west of Big Timber). A generalized irrigation water balance for the Boulder River Watershed is depicted graphically in Figure 11.

Figure 11. Boulder River Watershed Irrigation Water Budget.



*Note: includes about 400 acre-feet that is diverted by the City of Big Timber; city return flows would be to the Boulder River below the USGS gage or to the Yellowstone River.

The total efficiency of an irrigation system is the product of the conveyance and field efficiencies. The average conveyance efficiency from the ditch efficiency assessments was found to be 72 percent (28% of the water diverted did not reach a field; see Table 9). The average field efficiency for flood irrigation, based on assessments at five sites, was about 23 percent (Table 10). The resulting computed efficiency for flood irrigation in the watershed would be about 17 percent (0.72*0.23*100). This means that for each acre-foot of irrigation water consumed, about six acre-feet of water is diverted from the stream at the headgate.

Irrigation in the watershed is estimated to seasonally consume, through ET, about 1.1 acre-foot of water per acre irrigated (see page 18). To provide 1.1 feet of water to the crop for ET, at 17 percent efficiency, about 6.5 acre-feet of water would need to be diverted from the stream per acre.

The 6.5 acre-feet of water diverted per irrigated acre might seem high but the streamflow data seem to substantiate this estimate. In Table 2 inflow/outflow data show that about 6 acre-feet less water, per acre irrigated, was leaving the West Boulder River than entering it from the higher elevations. Some of this water was consumed by crops within the West Boulder watershed; most was probably diverted outside of the West Boulder watershed to irrigate land adjacent to the main Boulder River. Flow reductions from the lower section of the Boulder River also were found to be equivalent to about 6 acre-feet per acre irrigated. This would have included some water consumed by crop ET for fields in the Boulder River Valley proper; but most of the water was diverted outside of the watershed to irrigated lands to the east and west of Big Timber.

Another check on diversion estimates per acre irrigated can be made by computations using the ditch loss measurement data in Table 9. The summation of the measured diverted flows for the 13 ditches is 185 CFS, and these ditches supply water to about 4,545 acres. If the measured and summed diversion rates for these ditches are typical, this would be equivalent to about 367 acre-feet of water diverted per day, or about .081 feet (a little under 1 inch) per acre, per day. The irrigation season generally extends from about the first part of May until the end of September, but a 90-day period will be used here to account for down-time during haying and for reduced crop demands early and late in the season. Over a 90-day period, 185 CFS would accumulate to 33,000 acre-feet of water, or about 7.3 acre-feet per-acre. This is a little more than the overall 6.5 acre-feet per-acre estimate.

A check on whether the crop ET estimate of 1.1 acre-feet per-season is reasonable can be made by considering hay yields and associated water use. Conversations with ranchers indicated that hay yields for flood irrigation in the watershed typically are about 2.5-to-3 tons per-acre. Yields with sprinkler irrigation were considered to be higher, at about 3-to-4 tons per acre or more. Most crops grown in the watershed are alfalfa hay, grass hay, an alfalfa-grass hay mix,

or pasture grass. Average reported hay yields, for all irrigated hay types, for Sweet Grass County during the 2003-2006 season, were about 2.3 tons per acre (USDA, undated). Approximately 4-to-6 inches of water is used by ET for each ton of alfalfa hay produced (Montana State University, undated; Colorado State University, 2007). Given this, 3 tons of hay would require about 12-to-18 inches of water, and 2.5 tons would require about 10-to-15 inches of water.

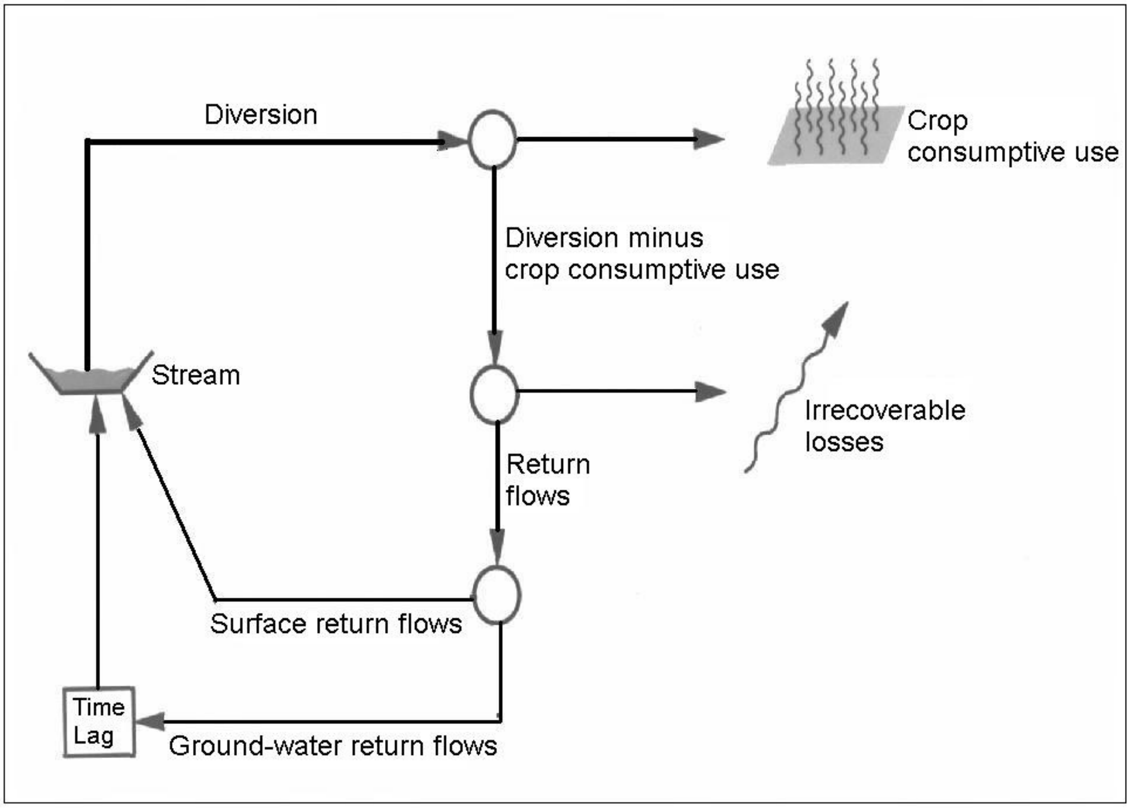
To produce the reported amounts of hay would require slightly more water than the 13 inches (1.1 foot) per-acre that is estimated to be added by irrigation. The additional water needed to explain the yields would be that added to the soil by precipitation. This could include precipitation water added during the fall, winter, and early spring that builds up soil moisture, or water added by rainfall that might occur during the growing season. Also, because crop yields usually are higher with sprinkler irrigation, the amount consumed on fields with these systems might be a little higher--perhaps about 18-24 inches per season. However, sprinkler irrigation only accounts for about 13 percent of the land irrigated with Boulder River water.

Irrigation Return Flows

One finding of this study is that only about 17 percent of the water diverted for irrigation from the Boulder River is used by the hay crop through ET. However, the remaining 83 percent of the water is not necessarily lost or wasted because most eventually returns to either the Boulder River and its tributaries, or the Yellowstone River. Figure 12 is a generalized irrigation water supply diagram depicting where the water diverted for irrigation can go. As was discussed in the ditch loss analyses, some of the water in a ditch is lost to seepage before it even reaches a field. Of the water that is applied to irrigate a field, some is retained in the soil and used by crops through ET. Most of the rest either percolates below the root zone, or runs off the bottom of the field as tail water. In the Boulder River watershed, most ditch seepage and deep percolation water from fields eventually reaches a shallow aquifer and returns to a stream as groundwater return flow. Depending on aquifer characteristics and the distance of the irrigation from a stream, it can take days or even months for groundwater return flows to reach a stream. But because the Boulder River valley is narrow and the underlying aquifers probably are composed of coarse glacial and alluvial deposits, it is likely that groundwater return flows usually come back to the river relatively quickly. Some of the water lost through inefficiencies is likely irrecoverable. This includes water that ponds in low spots and evaporates, water that seeps out and is consumed by phreatophytes near the margins of fields or along ditches, and water that evaporates from the surface of ditches. Surface return flows, from tail water at the end of fields or wastewater from the end of ditches, flows back to a stream

relatively quickly. Some ranchers also indicated they are able to capture and reuse the tail water further down on the ditch system.

Figure 12. Irrigation water use and return flow diagram.



Inefficient flood irrigation systems generally produce the most return flows. With flood irrigation, the irrigator's goal is to store as much water as possible in the soil so there is adequate moisture to meet the crop demand until the field can be flooded again. Because of this, flood irrigated fields generally are irrigated infrequently but the water is applied at a high rate during irrigation. In the Boulder River watershed, each flood irrigation probably adds about 3-to-6 inches of water to the soil that is later available to the crop. In comparison, a center-pivot sprinkler irrigation system might add about 1 inch of moisture to the soil during each rotation. Because sprinkler systems require less water to be applied per acre than flood systems, they are considered more efficient. However, return flows from sprinkler-irrigated fields will generally be less. It is also important to keep in mind that sprinkler irrigation usually improves field efficiencies, but may not change the conveyance efficiency of the system if the same ditch is used to supply the sprinkler as was used for the previous flood system.

Recommendations

Because irrigation efficiencies in the Boulder River watershed are low overall, there are opportunities for improvements. When deciding on whether or not to increase the efficiency of an irrigation system, operators need to consider the potential benefits and costs of doing so. Increasing irrigation efficiency often results in a more effective use of diverted water and, in turn, higher crop yields. More efficient or automated irrigation systems might also reduce labor costs. Another benefit for irrigators, who are receiving less water than they need to fully irrigate their crops, might be that they could stretch the available water a little further. Because most of the water that is diverted for inefficient irrigation eventually returns to a stream, efficiency improvements do not always increase streamflow. Lining ditches or installing more efficient field systems might even have unintended consequences, such as reducing the water going to wetland areas that are benefiting from inefficient irrigation. Operating a sprinkler system may also require power costs where there were none for a gravity-flood system.

Irrigation patterns in the Boulder River Watershed are changing. Many flood irrigators are changing from using field ditches and tarp dams to gated pipe. Ranchers are doing this because (1) it allows them to lengthen their sets and irrigate a bigger area with the same amount of water, (2) it is easier to distribute water uniformly across the field, (3) it may result in increased hay yields, and (4) they find it to be less labor intensive. Although it was not established conclusively in this project that gated pipe irrigation is more efficient (based on our few field efficiency assessments) most ranchers spoke positively of gated pipe. They believe, based on their experiences prior to and after switching, that irrigation with gated pipe is a more efficient way and that using it has increased their crop yields.

About 13 percent of the land in the watershed is sprinkler irrigated. Sprinkler irrigation usually requires that much less water be applied to the field per-acre than flood irrigation does. This should result in the need to divert less water from the river. However, the amount of water used by the crop will be about the same, or even a little higher, with a sprinkler system than with a flood system. This is because sprinkler systems are producing more hay per acre and, hence, the more robust crop consumes more water through the process of ET. There were several new center-pivot sprinkler systems installed in the watershed during the four years of this study. In most cases sprinklers are replacing standard flood irrigation systems, but in other instances they are replacing gated pipe, and wheel-line sprinkler systems are sometimes being replaced by center pivots.

The following are some recommendations and observations on potential efficiency and water management improvements that could be made in various areas of the Boulder River Watershed.

East Boulder River

East Boulder River flows usually are not sufficient during the late summer to meet all irrigation demands. Summertime irrigation demands on the stream were observed to have been about 40 CFS (1,600 inches), while August inflows during the study usually were 20-to-30 CFS (800 to 1200 inches). The result was that some irrigators were short on water and lower portions of the stream were dewatered during the late summer and early fall.

Ditch losses in the East Boulder River varied, but generally were in the moderate range. One exception was the Craft Ditch where losses were estimated at over 60 percent. These high losses could be reduced through ditch repair or lining, although it is likely that most of the water seeping out of the Craft Ditch will be reused because it should eventually return to the middle sections of the East Boulder River. Almost all of the fields in the East Boulder River watershed are flood irrigated and efficiencies are low overall. Improving field and ditch efficiencies might improve the water supply for some junior users in the East Boulder Watershed. For instance, increased efficiencies could reduce the amount of water that needs to be diverted down some of the senior ditches. However, because of the water shortages on the East Boulder, it is likely that most of this saved water would quickly be diverted by junior users downstream.

Some land that is irrigated by the Miles-Decker and Boe-Engle Ditches is adjacent to the Boulder River proper. Irrigation return flows from this land, and those from the lowermost irrigated land in the East Boulder watershed, mostly return to the main Boulder River. Also, some return flow from the Tolhurst ditch does not return to the East Boulder River because it is captured by the Miles-Decker Ditch. Efficiency improvements on these irrigated lands and ditches might improve flow in the lower East Boulder River, because less water would need to be diverted from the stream while return flows to the East Boulder would not be reduced. Another consideration is that it might be possible to irrigate some of this land with Boulder River water, rather than East Boulder water. However, this would require water-rights changes and possibly new ditches or pump stations, with resulting costs.

Efficiency improvements alone would probably not be sufficient to keep the East Boulder River from being dewatered during the late summer of dry years. This is because the irrigation demand is much higher than the flow of the East Boulder during the late summer of dry years, and any water saved by improvements would likely be used by irrigators who are presently short of water. Leasing irrigation water for instream flow, perhaps in conjunction with efficiency

improvements, might be a way to keep a minimum flow in the lower East Boulder River.

West Boulder River

The water supply in the West Boulder River is greater than that in the East Boulder. Irrigation return flows appear, to some degree, to add back flow so that by late summer depletions are low relative to natural inflows. Although there is water in the stream during late summer, some irrigators on some ditches may still run short of water because the rocky stream channel seems to limit their ability to divert water when the flows are lowest.

Ditch losses were found to be moderate-to-high in the West Boulder River watershed. Although much of the ditch loss probably returns to the West Boulder River, high losses could result in less than optimal water deliveries to fields at the lower end of a ditch system. With this in mind, controlling losses through ditch repairs and possibly lining some segments could result in a better water supply to some fields and improved crop yields.

All irrigated land in the West Boulder River watershed is flood irrigated. Much of the irrigation already has been improved by the installation of gated pipe. Because most of the irrigated lands in the West Boulder Watershed are not too distant from the stream, it is likely that return flows from inefficient irrigation re-enter the river relatively quickly. The West Boulder River is similar to the East Boulder River in that some land irrigated with West Boulder River water is adjacent to the Boulder River proper. Improving irrigation efficiencies on this land would result in the need to divert less water, and possibly higher flow in the lower West Boulder River.

Upper and Middle Boulder Rivers

The irrigated land base above the Boulder River Forks is relatively small and mostly supplied with water from the McLeod Mutual and Bruffey Ditches. Ditch losses in the McLeod Mutual Ditch were measured and found to be about average. Potential places where improvements could be made have been noted in the field assessment for that ditch. During recent years, several center pivot and wheel-line sprinkler irrigation systems have been installed in this portion of the watershed. Efficiency improvements on other flood irrigated fields could improve crop yields but would only have a small effect on the flow of the upper Boulder River. This is because irrigation withdrawals here are small in comparison to river flows and because return flows from inefficient irrigation probably come back to the river relatively quickly.

Irrigation on the middle sections of the Boulder River is primarily with flood systems and gated-pipe flood systems. Ditch losses were found to be moderate. In the water supply section of this report, it

was found that the middle sections of the Boulder River are gaining water. This water probably is irrigation returns from land irrigated with East Boulder and West Boulder river water (but that is adjacent to the Boulder River proper) or waste-water from the end of irrigation ditches that originate in these tributary watersheds.

Field efficiencies are probably low overall in this section of the watershed. Because all irrigation in this segment of the valley is very close to the river, it is likely that the return flows from inefficient irrigation come back to the river rather quickly. Improving efficiencies here might have little effect on river flows, but could benefit ranchers by increasing hay yields and decreasing labor requirements.

Lower Boulder River

Ditches that divert water from the lower five miles of the Boulder River serve about 6,300 acres of irrigation. Some of this irrigation is bordering the Boulder River and return flows from this land go to the Boulder River. The remaining irrigation is to the east and west of Big Timber and topographically in the Yellowstone River Valley. Return flow from this irrigation, except for some initial ditch losses in the Boulder Valley, will eventually return to the Yellowstone River.

Seepage losses from these lower ditches were moderate-to-high. These losses could be reduced through repairs, lining, or by periodically sealing the ditches with polymer-type sealers. Water saved by doing so could be used to decrease shortages that occur at the lower ends of some of the ditches. Saved water could also be left in the river to improve flows for fisheries in the lower Boulder River.

Most land that is irrigated with water from the lower ditches is flood irrigated. Gated pipe is being used to irrigate some of this land and some sprinkler systems have been installed. However, there is still a substantial irrigated land base where efficiency improvements could be made. Improving field efficiencies would increase hay yields and potentially improve the water supply for users further down the ditch. Because return flows from most of this irrigation go to the Yellowstone rather than the Boulder River, water savings due to improved efficiencies could reduce diversion requirements at the headgate and thereby improve streamflows in the lower Boulder River.

Potential ditch efficiency improvements

Ditch losses were estimated to average about 28 percent, with much higher rates measured on some ditches. There are several ways that ditch losses could be reduced. Many ditches were in poor repair; grades were low and there were areas where water was backing up due to undersized culverts or constriction at other types of crossings. Where a ditch is constricted, water backs up and seepage is

increased. Improving crossings and bringing ditches back to grade could decrease seepage losses. In some areas, where cattle were watering along the ditch, the banks were trodden causing the ditch to widen. Widening increases the wetted perimeter of the ditch which can lead to more seepage. Ditch banks in these damaged sections could be reestablished and specific reinforced access areas constructed for the cattle to water at. The canal conditions surveys contain specific recommendations for these types of improvements for some of ditches.

Polymer sealers are another way to control ditch losses. These are sprayed on each year in the spring before the ditch is turned on. They are relatively inexpensive, and have been found effective in other areas of Montana. There are some concerns though regarding the potential effects of these sealers on fish and other aquatic life that would need to be addressed. More permanent liners could be installed in shorter sections of ditches where seepage losses are particularly high.

Other Observations

While walking ditches during the canal efficiency assessments, it was noted that there were some hay fields or small pastures where water was simply allowed to run onto the field but with no attempt to distribute it evenly. In some cases the ground was just too rough or there were too many high and low spots to allow for effective flood irrigation. Sprinkler systems might be suitable for some of these fields, where the soils are productive. In some cases though, the soils were stony and of poor quality and the benefits of irrigating these lands probably is low. These marginal lands might be removed from irrigation and the water right possibly changed so that it could be used to irrigate more productive ground. Another option might be to lease the water rights for these marginal grounds to an instream flow use. This could protect the water right and might also compensate the owner financially for any production losses.

It might be possible to install small off-stream storage reservoirs near the mouths of some of the coulees below some of the larger ditches, such as the Dry Creek Canal. Water could be fed into these small reservoirs during peak runoff, when it is abundant, and released to meet irrigation demands during the late summer when available flows are much lower. In some cases, it might be possible to locate a small reservoir at a high enough elevation to provide the pressure needed to operate a sprinkler irrigation system. Engineering and environmental assessments would be required to determine if there are any suitable sites where sufficient quantities of water could be safely stored and where seepage losses from a reservoir would not be excessive.

During the canal seepage loss assessments, some of the river headgates were found to be in poor condition and there seldom were

water measuring devices at the headgates or further down the ditches. By giving the users the ability to control their diversions and to monitor water usage, improved headgates in conjunction with measuring devices could lead to more efficient water use and better water distribution between users on shared ditches.

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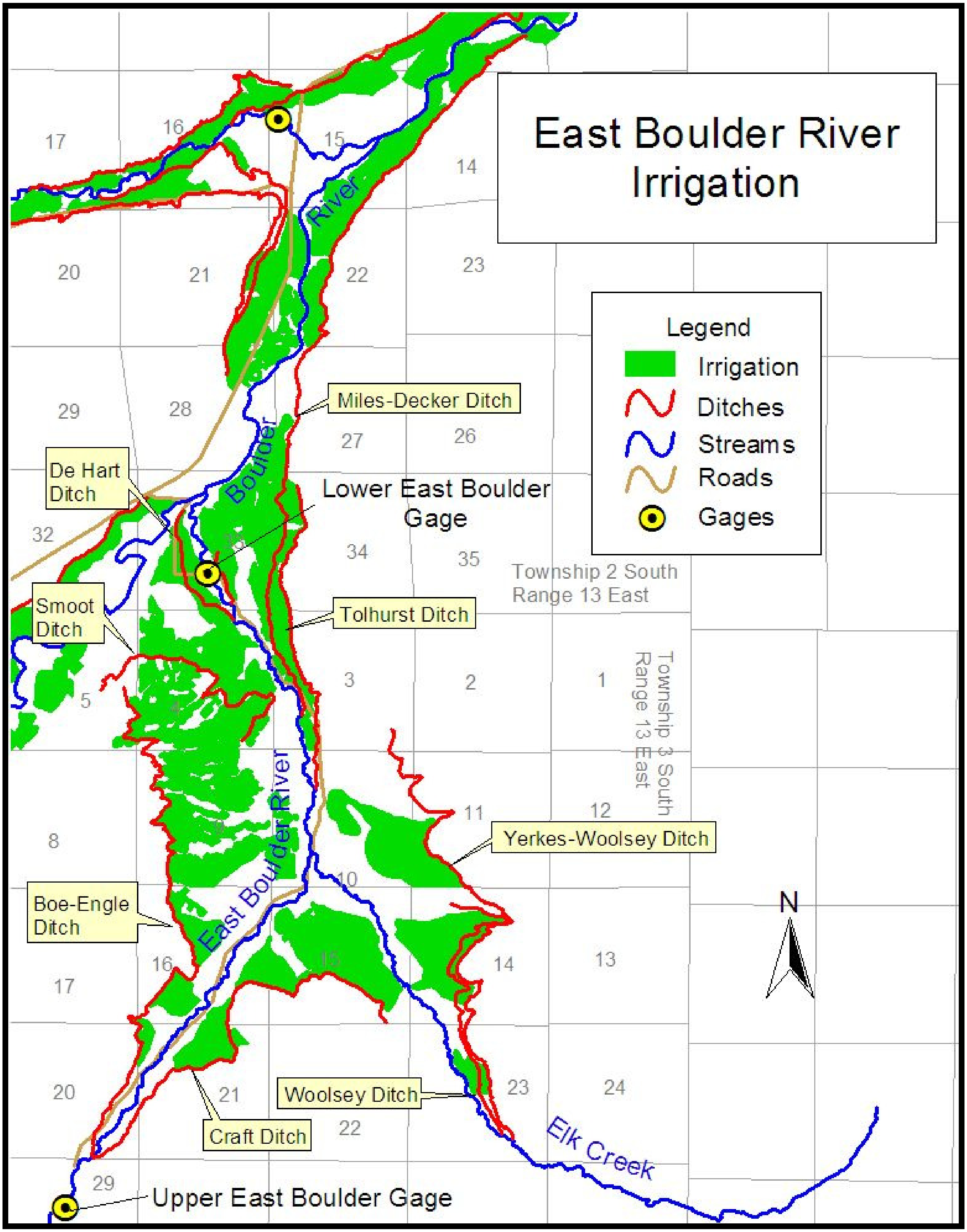
Contributors

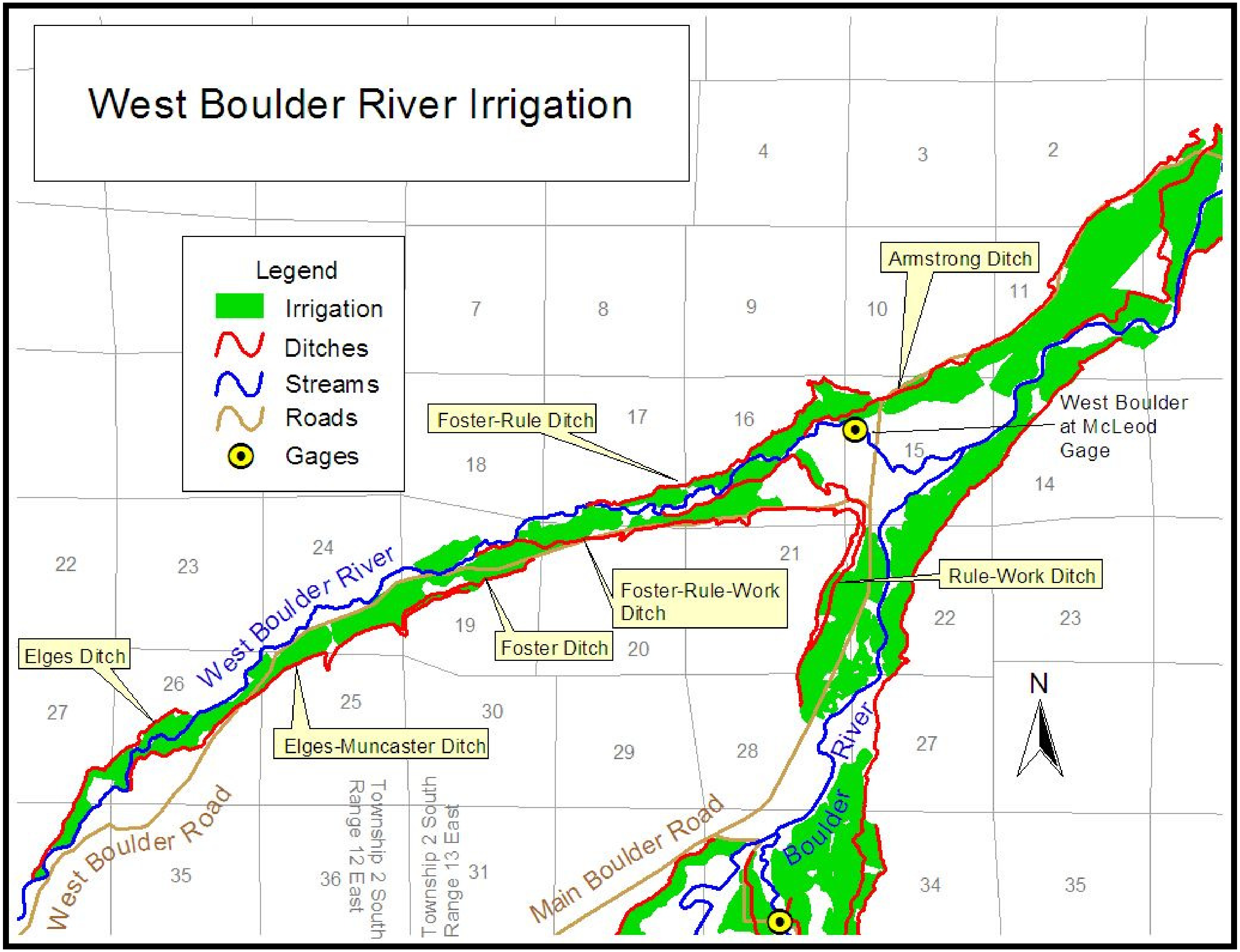
Larry Dolan of the Montana Department of Natural Resources and Conservation prepared this report with the assistance of the Boulder River Watershed Association. Chris Mehus, the Boulder River Watershed Association Coordinator at the time, initiated this study and was instrumental in securing funding and the help of DNRC. Coral Wilson of the Sweet Grass County Conservation District and the Association kept the project alive and the Association informed and interested. Joe Hansen of the Association also was instrumental in getting the project started and in obtaining landowner permission to install the stream gaging stations. Much of the field work for this project was done by Steve Roloff, or with Steve's assistance. Steve worked as a summer intern on the project during the 2003, 2004, and 2005 seasons and also helped out with the GIS aspects of the project. His dedication to the project and good company were appreciated throughout. Most of all, this project would never have been possible without the help and cooperation of all the participating landowners, ranchers, and ranch managers in the watershed. Terry Amadon provided access for the upper East Boulder River gage, was a careful observer of the stream, and always a source of first-rate conversation. Geoff Walton made access to the lower Boulder River DNRC gage possible, and Geoff was always friendly and helpful to us, and interested in the project. Carl Wilsey allowed us to access the lower East Boulder River gage and the ranch managers for the Beaver Meadows Ranch graciously allowed us access to the upper Boulder gage just downstream of the Natural Bridge. Thanks also to Tom Brownlee, Emma Ellison, Keith Engle, Roger Engle, and Stuart Stenberg for their cooperation with the field irrigation efficiency assessments. It was always a pleasure to work and visit with these folks, and we never would have been able to fully understand how irrigation in the valley works without them.

Appendix A: Boulder River Watershed Irrigated Lands Inventory Maps and Information.

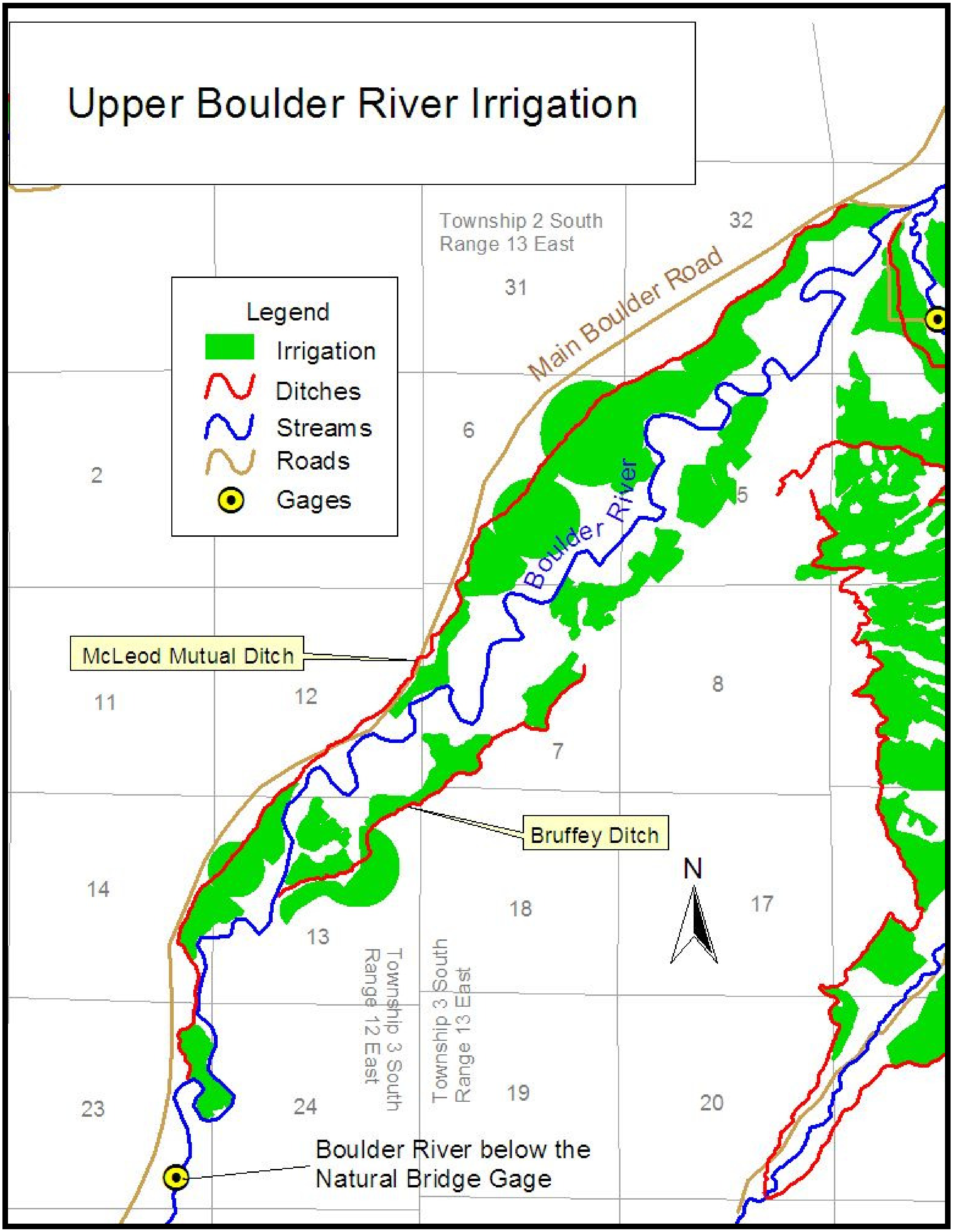
Map A-1. East Boulder River irrigation.



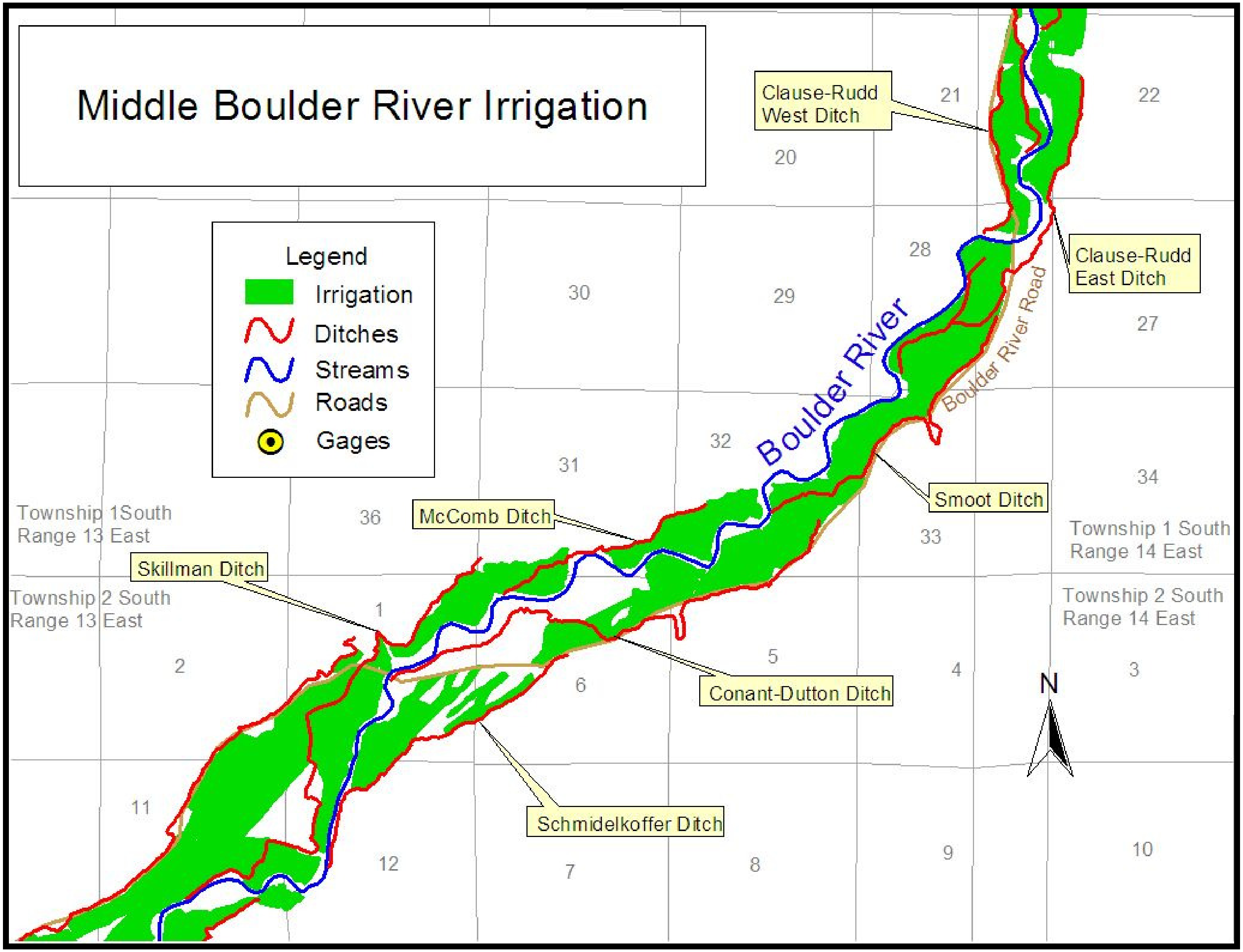
Map A-2. West Boulder River irrigation.



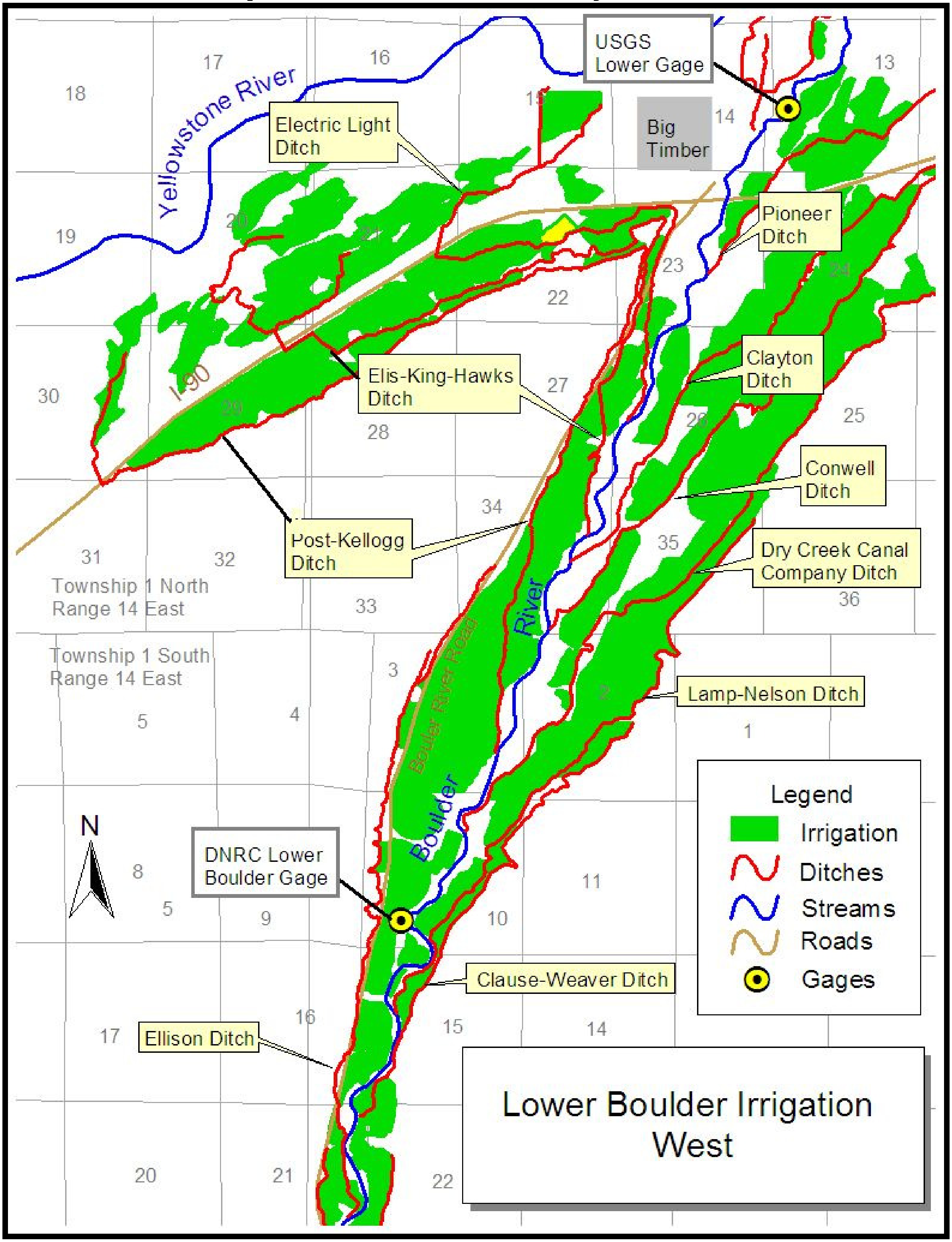
Map A-3. Upper Boulder River irrigation.



Map A-4. Middle Boulder River irrigation.



Map A-5. Lower Boulder River irrigation west.



Map A-6. Lower Boulder River irrigation east.

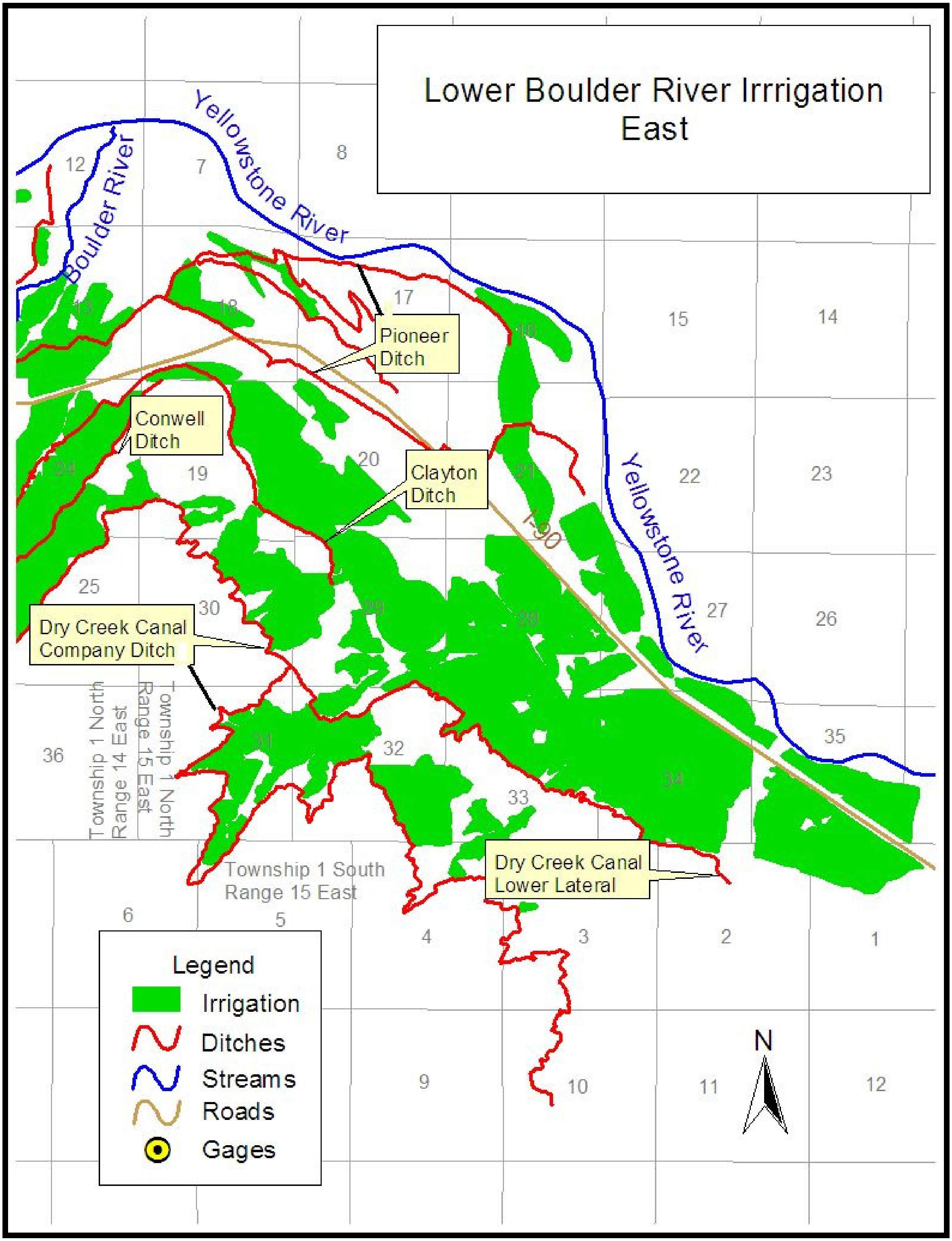


Table A-1. Boulder River Watershed irrigation ditches and approximate acres irrigated by ditch.

Ditch	Source	Acres Irrigated
Armstrong	West Boulder River	413
Boe-Engle	East Boulder River	700
Bruffey	Boulder River	137
Clause-Rudd	Boulder River	181
Cause-Rudd West	Boulder River	70
Clause-Weaver	Boulder River	86
Clayton	Boulder River	571
Conate Dutton	Boulder River	171
Conwell	Boulder River	286
Craft	East Boulder River	338
DeHart	East Boulder River	77
Dry Creek Canal Company	Boulder River	3,312
Electric Light	Boulder River	254
Elges	West Boulder River	61
Elges-Mucaster	West Boulder River	138
Elis-King-Hawks	Boulder River	721
Ellison	Boulder River	672
Flowers	East Boulder River	117
Foster	West Boulder River	84
Foster-Rule	West Boulder River	85
Foster-Rule-Work	West Boulder River	118
Hogan	Boulder River	18
Lamp-Nelson	Boulder River	439
LW Ranch	Boulder River	14
McComb	Boulder River	88
McLeod Mutual	Boulder River	510
Miles-Decker	East Boulder River	411
Murray-Newspalmer	Boulder River	65
Pioneer	Boulder River	549
Post-Kellog	Boulder River	663
Rule-Work	West Boulder River	208
Schmidelkofer	Boulder River	122
Skillman	Boulder River	204
Smoot	Boulder River	151
Smoot (East Boulder)	East Boulder River	147
Tolhurst	East Boulder River	106
Unnamed	West Boulder River	26
Wilson	Nuttal Creek	33
Woolsey	Elk Creek	347
Total Acres		12,693

Appendix B: 2003-2006 DNRC Streamflow data and comparison graphs for the Boulder River Watershed.

Figure B-1. Streamflows for the upper Boulder River gage (2003-2006).

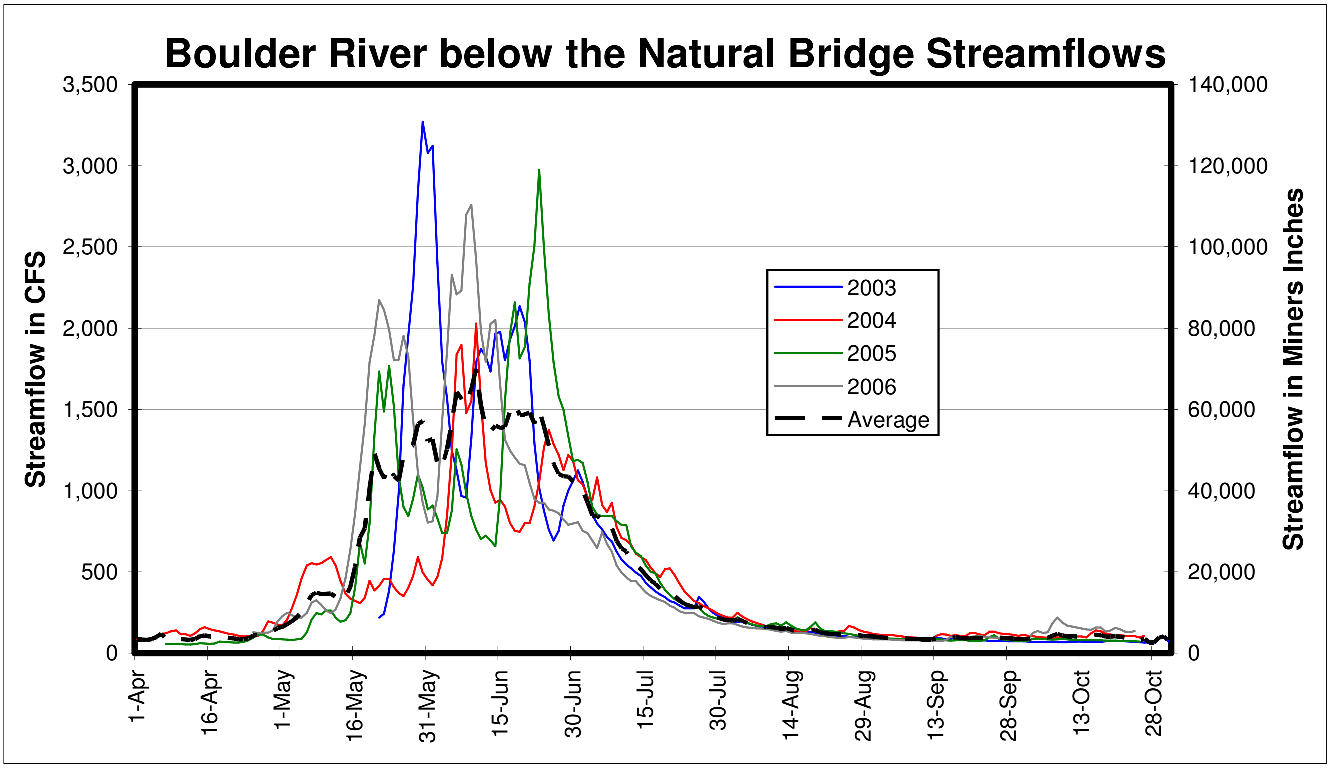


Figure B-2. Streamflows for the DNRC lower Boulder River gage (2003-2006).

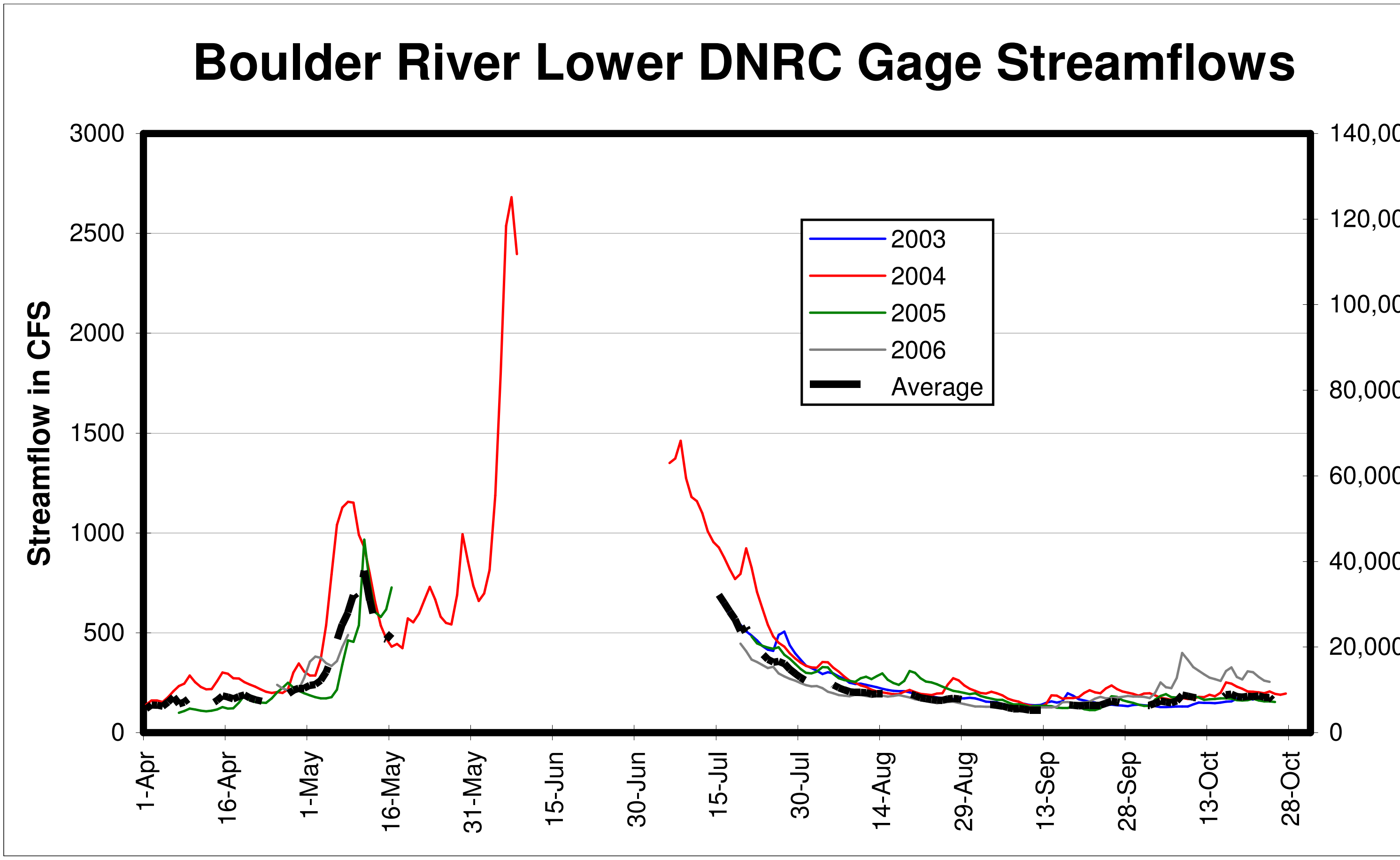


Figure B-3. Streamflows for the upper East Boulder River gage (2003-2006).

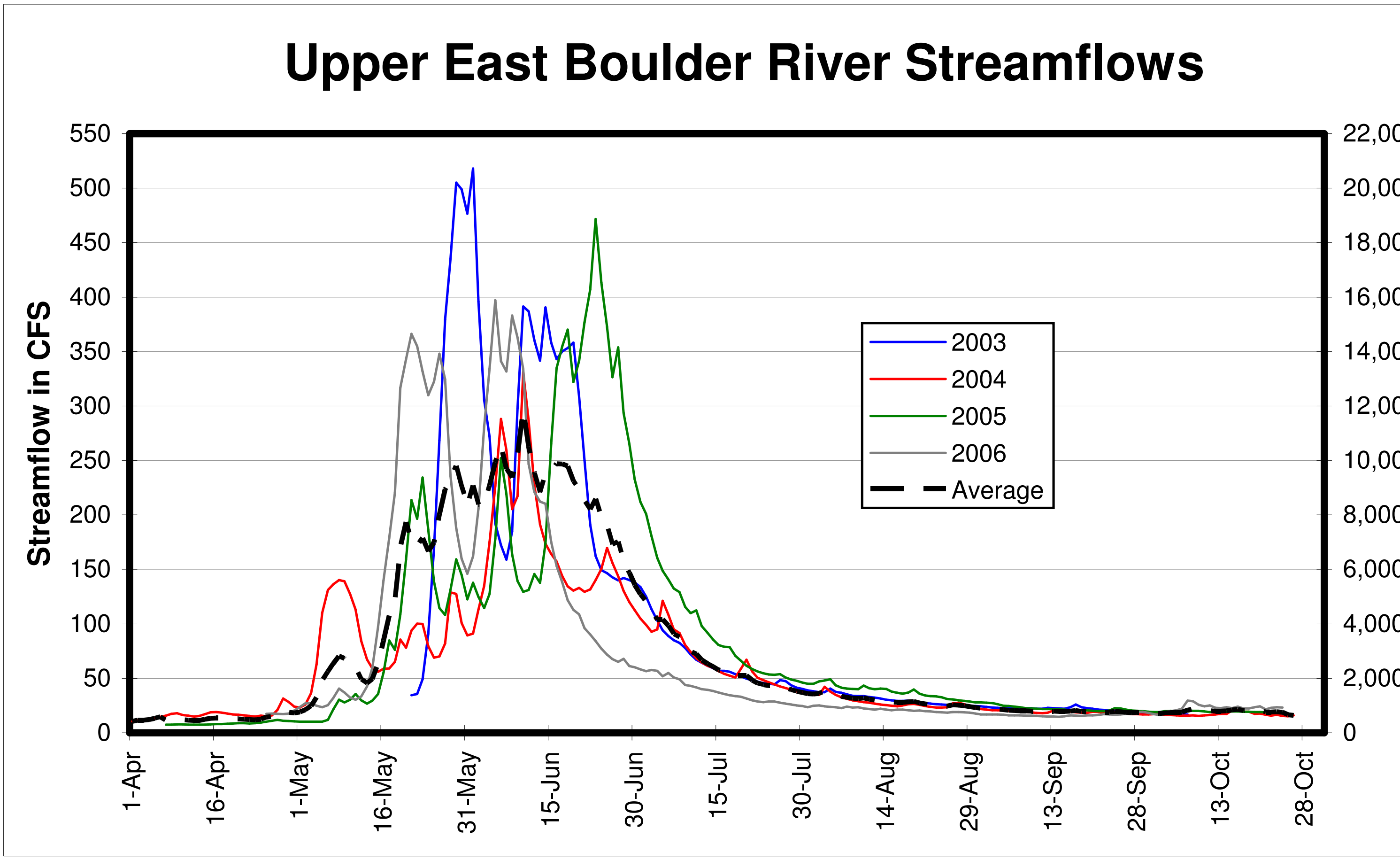


Figure B-4. Streamflows for the lower East Boulder River gage (2003-2006).

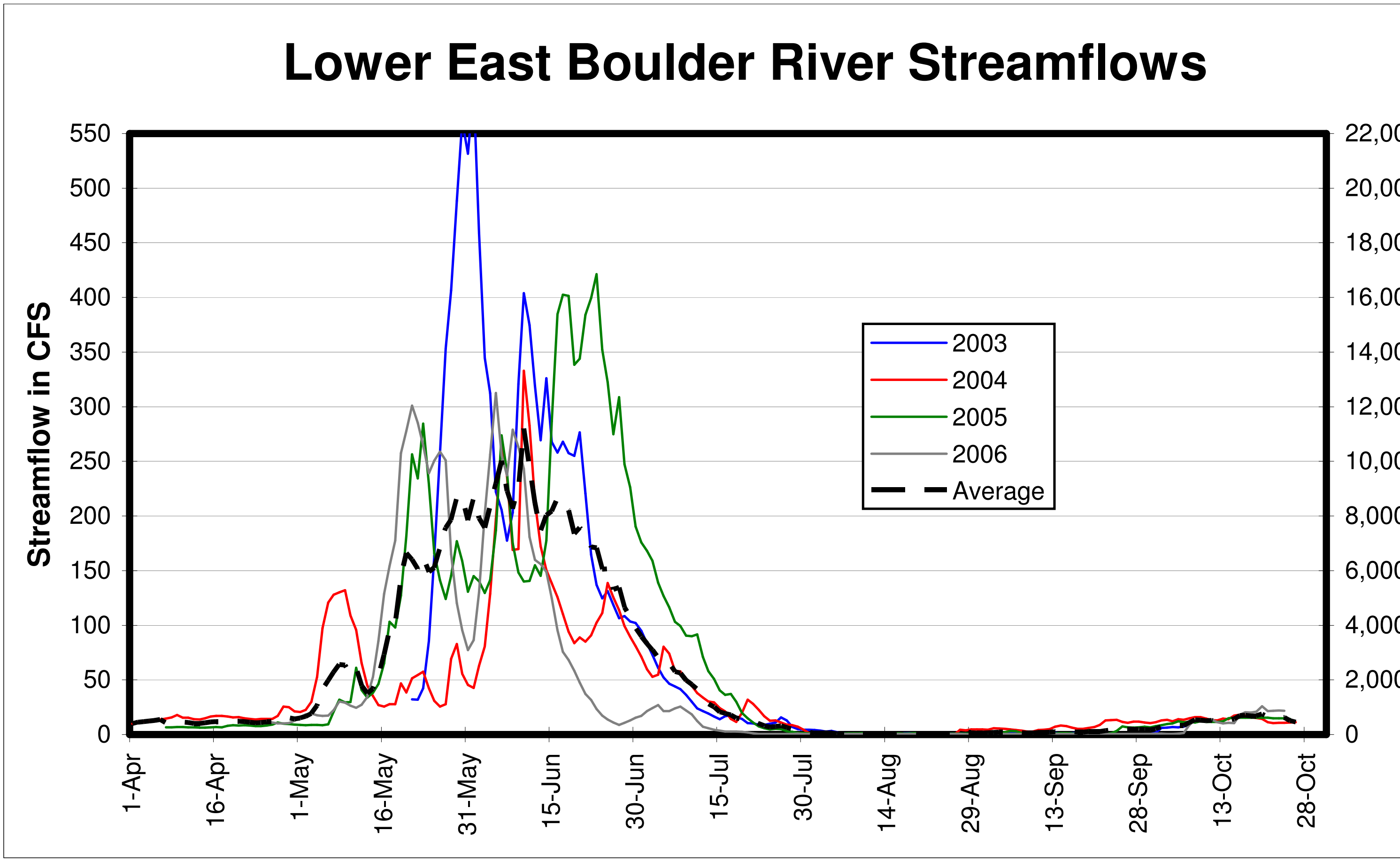


Figure B-5. Streamflows for the upper West Boulder River gage (2003-2006).

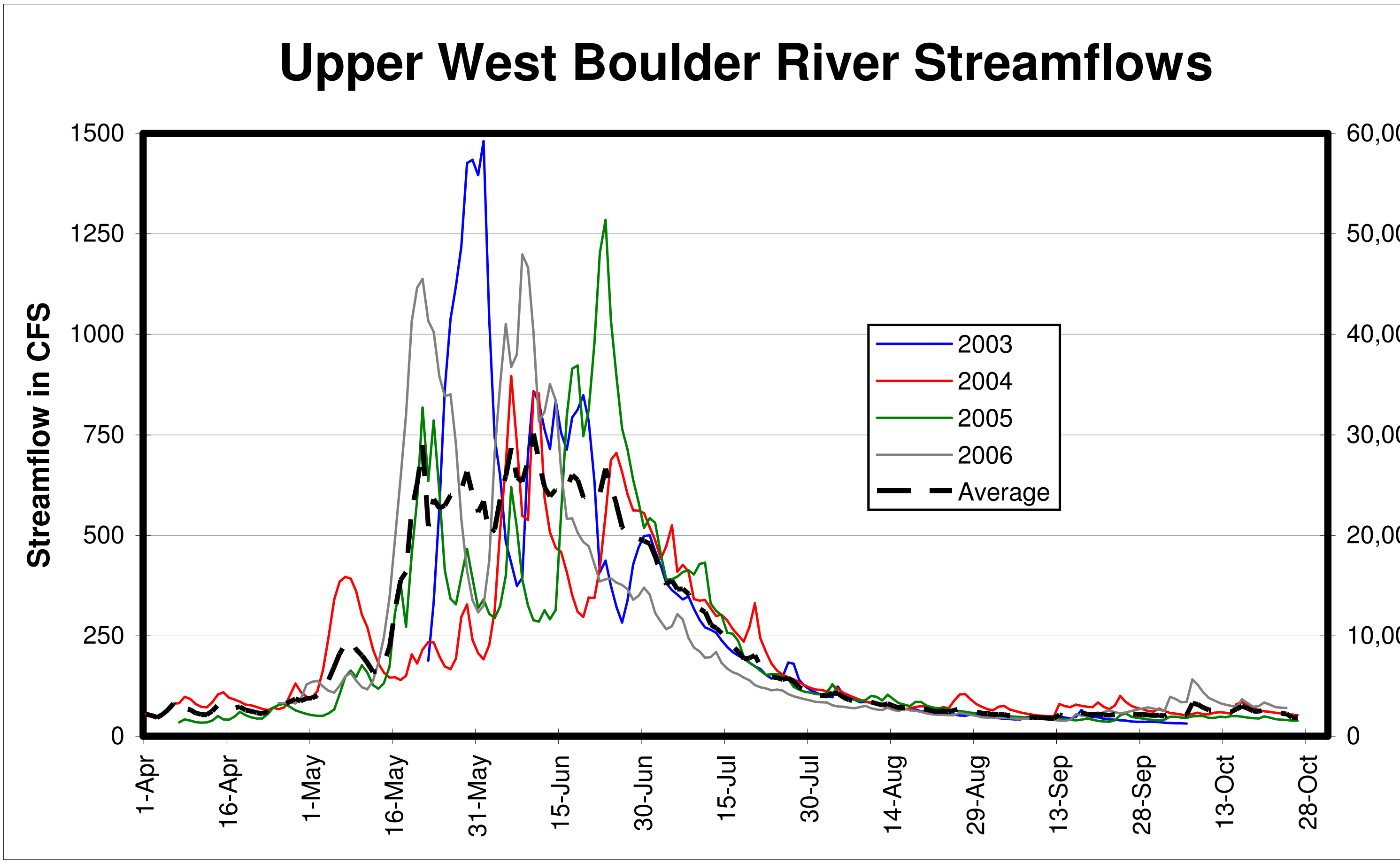


Figure B-6. Streamflows for the lower West Boulder River gage (2003-2006).

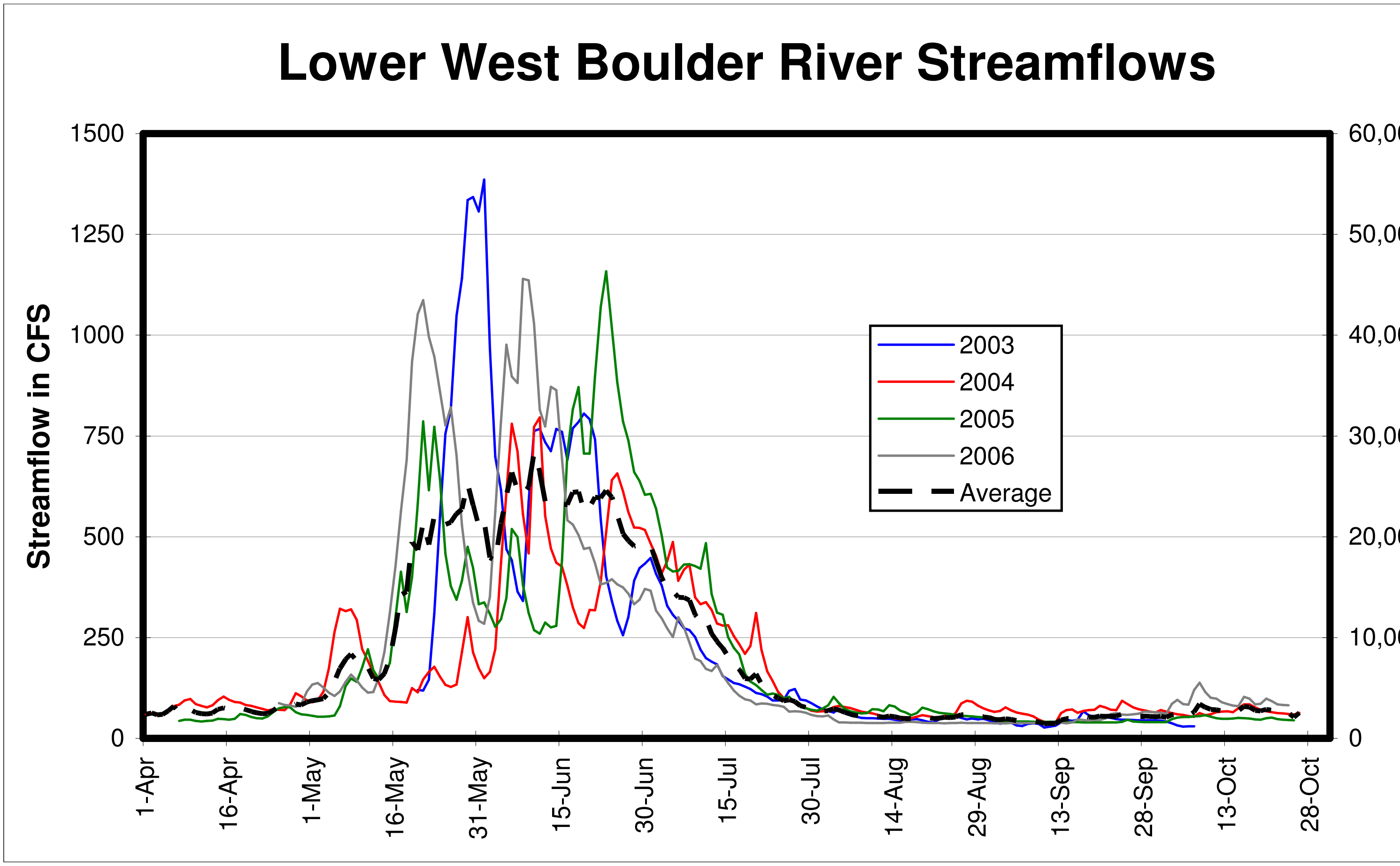


Table B-1. Daily average streamflows for the Boulder River below the Natural Bridge gage.

Daily Average Streamflows in Cubic Feet Per Second (CFS) by year									
Day	**2003**	**2004**	**2005**	**2006**	***Day***	**2003**	**2004**	**2005**	**2006**
April 1		83			***June 1***	3,122	418	909	813
April 2		83			***June 2***	2,402	468	829	966
April 3		80			***June 3***	1,791	586	738	1,436
April 4		85			***June 4***	1,571	845	738	1,859
April 5		100			***June 5***	1,246	1,238	877	2,327
April 6		119			***June 6***	1,125	1,839	1,256	2,208
April 7		122	54		***June 7***	967	1,897	1,162	2,231
April 8		134	58		***June 8***	959	1,477	984	2,699
April 9		140	58		***June 9***	1,324	1,551	845	2,760
April 10		117	55		***June 10***	1,791	2,028	760	2,419
April 11		117	52		***June 11***	1,872	1,551	701	1,982
April 12		108	53		***June 12***	1,826	1,172	723	1,793
April 13		122	55		***June 13***	1,735	1,002	694	2,026
April 14		148	61		***June 14***	1,966	926	659	2,049
April 15		160	60		***June 15***	1,978	943	967	1,653
April 16		148	58		***June 16***	1,803	902	1,549	1,315
April 17		140	60		***June 17***	1,930	799	1,965	1,247
April 18		134	71		***June 18***	2,014	753	2,159	1,204
April 19		127	70		***June 19***	2,136	746	1,814	1,166
April 20		119	67		***June 20***	2,038	799	1,883	1,157
April 21		115	66		***June 21***	1,803	799	2,272	1,049
April 22		106	64		***June 22***	1,295	902	2,506	949
April 23		102	69		***June 23***	1,018	1,054	2,975	925
April 24		104	79		***June 24***	876	1,267	2,493	925
April 25		104	95	129	***June 25***	760	1,375	2,086	885
April 26		108	114	124	***June 26***	694	1,286	1,791	877
April 27		137	114	127	***June 27***	753	1,219	1,581	861
April 28		195	97	127	***June 28***	909	1,126	1,497	821
April 29		188	87	140	***June 29***	1,001	1,219	1,334	790
April 30		175	87	197	***June 30***	1,062	1,181	1,180	798
May 1		172	84	230	***July 1***	1,125	1,063	1,190	806
May 2		209	82	250	***July 2***	1,053	1,037	1,171	753
May 3		281	81	234	***July 3***	959	960	1,054	738
May 4		360	84	218	***July 4***	853	943	901	694
May 5		463	89	218	***July 5***	798	1,081	853	645
May 6		541	129	250	***July 6***	760	910	845	745
May 7		553	207	311	***July 7***	716	869	845	673
May 8		547	246	325	***July 8***	687	926	845	625
May 9		553	238	297	***July 9***	625	776	813	540
May 10		573	262	262	***July 10***	578	709	790	497
May 11		592	262	246	***July 11***	546	695	790	467
May 12		541	218	270	***July 12***	522	667	659	444
May 13		445	193	337	***July 13***	497	612	618	444
May 14		365	204	462	***July 14***	474	592	598	406
May 15		336	246	639	***July 15***	434	573	540	374
May 16		321	406	863	***July 16***	407	528	503	354
May 17		307	680	1,143	***July 17***	380	492	491	339
May 18		340	552	1,411	***July 18***	360	468	433	325
May 19		445	798	1,790	***July 19***	345	516	390	315
May 20		386	1,334	1,956	***July 20***	321	522	359	292
May 21	220	412	1,735	2,172	***July 21***	312	480	334	279
May 22	243	457	1,486	2,113	***July 22***	294	429	315	258
May 23	385	457	1,768	1,992	***July 23***	276	381	301	250
May 24	632	407	1,518	1,804	***July 24***	276	350	297	246
May 25	984	370	1,089	1,807	***July 25***	276	321	288	246
May 26	1,646	350	901	1,953	***July 26***	345	307	279	226
May 27	1,954	402	845	1,828	***July 27***	317	289	250	218
May 28	2,261	474	950	1,435	***July 28***	276	276	230	211
May 29	2,835	592	1,098	1,114	***July 29***	247	259	218	200
May 30	3,270	498	1,019	925	***July 30***	228	243	211	186
May 31	3,079	451	885	804	***July 31***	217	228	204	180

Table B-1. Daily average streamflows for the Boulder River below the Natural Bridge gage (Continued).

Daily Average Streamflows in Cubic Feet Per Second (CFS) by year									
Day	**2003**	**2004**	**2005**	**2006**	**Day**	**2003**	**2004**	**2005**	**2006**
Aug 1	209	220	204	183	**Oct 1**	72	112	73	87
Aug 2	195	220	200	183	**Oct 2**	71	108	76	87
Aug 3	192	247	222	173	**Oct 3**	70	104	89	124
Aug 4	199	224	204	164	**Oct 4**	69	100	89	135
Aug 5	185	209	186	157	**Oct 5**	69	98	87	124
Aug 6	176	195	176	154	**Oct 6**	69	96	84	129
Aug 7	166	185	170	151	**Oct 7**	69	94	82	183
Aug 8	160	175	167	151	**Oct 8**	68	98	84	218
Aug 9	157	166	167	149	**Oct 9**	67	92	87	190
Aug 10	157	163	180	143	**Oct 10**	67	96	84	170
Aug 11	152	157	183	135	**Oct 11**	70	100	81	164
Aug 12	146	151	170	132	**Oct 12**	71	102	81	157
Aug 13	143	145	190	135	**Oct 13**	71	102	81	151
Aug 14	138	140	170	127	**Oct 14**	70	98	81	146
Aug 15	133	134	151	122	**Oct 15**	69	122	81	143
Aug 16	133	132	143	127	**Oct 16**	69	140	81	157
Aug 17	130	134	140	122	**Oct 17**	70	134	79	157
Aug 18	130	154	160	119	**Oct 18**	72	122	77	132
Aug 19	125	145	190	112	**Oct 19**	75	115	77	140
Aug 20	120	137	151	108	**Oct 20**	75	110	77	154
Aug 21	116	132	137	103	**Oct 21**	74	110	76	146
Aug 22	114	127	135	99	**Oct 22**	72	106	74	132
Aug 23	109	129	132	97	**Oct 23**	71	106	73	129
Aug 24	107	134	129	93	**Oct 24**	70	104	73	135
Aug 25	105	137	122	95	**Oct 25**	68	98	71	
Aug 26	101	169	119	99	**Oct 26**	66	108		
Aug 27	99	157	112	97	**Oct 27**	66			
Aug 28	101	142	108	93	**Oct 28**	66			
Aug 29	101	132	103	89	**Oct 29**	93			
Aug 30	101	127	103	87	**Oct 30**	103			
Aug 31	99	119	105	86	**Oct 31**	71			
Sept 1	95	115	101	86					
Sept 2	92	110	95	86					
Sept 3	90	110	91	84					
Sept 4	88	110	89	82					
Sept 5	87	106	89	81					
Sept 6	85	102	87	79					
Sept 7	90	100	86	79					
Sept 8	92	98	84	79					
Sept 9	93	94	82	79					
Sept 10	88	92	81	79					
Sept 11	88	88	81	77					
Sept 12	90	87	82	76					
Sept 13	97	106	86	74					
Sept 14	92	117	84	73					
Sept 15	87	115	79	81					
Sept 16	87	108	77	101					
Sept 17	109	110	79	95					
Sept 18	99	106	82	89					
Sept 19	88	104	81	89					
Sept 20	85	122	76	87					
Sept 21	82	124	74	101					
Sept 22	82	115	74	108					
Sept 23	79	110	79	101					
Sept 24	76	132	99	97					
Sept 25	76	132	110	95					
Sept 26	75	122	89	95					
Sept 27	74	119	82	97					
Sept 28	72	117	81	97					
Sept 29	72	112	77	95					
Sept 30	72	108	74	91					

Table B-2. Daily average streamflows for the Boulder River Lower DNRC gage.

Daily Average Streamflows in Cubic Feet Per Second (CFS) by year									
Day	***2003***	***2004***	***2005***	***2006***	***Day***	***2003***	***2004***	***2005***	***2006***
April 1		139			***June 1***		660		
April 2		162			***June 2***		698		
April 3		161			***June 3***		814		
April 4		154			***June 4***		1,188		
April 5		177			***June 5***		1,799		
April 6		207			***June 6***		2,538		
April 7		233	99		***June 7***		2,680		
April 8		246	108		***June 8***		2,396		
April 9		286	121		***June 9***				
April 10		253	116		***June 10***				
April 11		229	110		***June 11***				
April 12		217	106		***June 12***				
April 13		219	109		***June 13***				
April 14		258	116		***June 14***				
April 15		301	129		***June 15***				
April 16		295	121		***June 16***				
April 17		272	122		***June 17***				
April 18		270	151		***June 18***				
April 19		253	187		***June 19***				
April 20		241	163		***June 20***				
April 21		231	153		***June 21***				
April 22		217	151		***June 22***				
April 23		205	149		***June 23***				
April 24		199	172		***June 24***				
April 25		204	202	240	***June 25***				
April 26		199	225	222	***June 26***				
April 27		217	250	212	***June 27***				
April 28		301	226	215	***June 28***				
April 29		347	209	217	***June 29***				
April 30		305	197	274	***June 30***				
May 1		286	187	355	***July 1***				
May 2		287	178	381	***July 2***				
May 3		367	172	375	***July 3***				
May 4		538	172	348	***July 4***				
May 5		792	177	334	***July 5***				
May 6		1,040	216	358	***July 6***		1,350		
May 7		1,128	341	428	***July 7***		1,372		
May 8		1,156	462	488	***July 8***		1,462		
May 9		1,151	454		***July 9***		1,273		
May 10		990	537		***July 10***		1,180		
May 11		927	967		***July 11***		1,159		
May 12		798	746		***July 12***		1,098		
May 13		655	603		***July 13***		1,008		
May 14		536	580		***July 14***		954		
May 15		471	617		***July 15***	681	928		
May 16		431	727		***July 16***	639	876		
May 17		444			***July 17***	596	819		
May 18		424			***July 18***	555	770		
May 19		572			***July 19***	540	795		446
May 20		552			***July 20***	508	922		408
May 21		596			***July 21***	486	827	482	365
May 22		664			***July 22***	462	704	447	354
May 23		730			***July 23***	433	622	435	339
May 24		667			***July 24***	415	540	426	324
May 25		581			***July 25***	409	482	420	330
May 26		550			***July 26***	489	451	427	297
May 27		541			***July 27***	505	431	390	282
May 28		689			***July 28***	439	397	370	269
May 29		993			***July 29***	397	372	344	260
May 30		857			***July 30***	366	351	319	248
May 31		735			***July 31***	336	334	300	237

Table B-2. Daily average streamflows for the Boulder River Lower DNRC gage (Continued).

Daily Average Streamflows in Cubic Feet Per Second (CFS) by year									
Day	***2003***	***2004***	***2005***	***2006***	***Day***	***2003***	***2004***	***2005***	***2006***
Aug 1	323	326	296	232	***Oct 1***	137	196	134	179
Aug 2	310	325	305	234	***Oct 2***	136	197	134	173
Aug 3	294	353	328	223	***Oct 3***	132	186	165	199
Aug 4	303	352	327	205	***Oct 4***	128	175	183	251
Aug 5	297	325	294	197	***Oct 5***	127	171	192	227
Aug 6	281	306	272	189	***Oct 6***	129	164	178	223
Aug 7	270	282	263	186	***Oct 7***	130	161	176	273
Aug 8	250	260	259	182	***Oct 8***	131	174	177	399
Aug 9	244	249	255	190	***Oct 9***	131	169	184	365
Aug 10	246	237	272	188	***Oct 10***	141	169	184	328
Aug 11	239	229	280	183	***Oct 11***	150	179	176	309
Aug 12	233	215	268	179	***Oct 12***	150	177	164	293
Aug 13	228	206	283	186	***Oct 13***	150	189	168	276
Aug 14	220	202	297	186	***Oct 14***	147	182	168	268
Aug 15	214	197	265	180	***Oct 15***	150	200	172	259
Aug 16	210	192	248	184	***Oct 16***	155	252	172	308
Aug 17	208	193	239	187	***Oct 17***	156	245	170	327
Aug 18	208	205	259	183	***Oct 18***	171	230	163	278
Aug 19	202	214	309	176	***Oct 19***	180	219	161	266
Aug 20	195	203	299	167	***Oct 20***	172	207	163	307
Aug 21	188	194	273	162	***Oct 21***	165	205	170	303
Aug 22	187	191	257	157	***Oct 22***		202	161	279
Aug 23	181	188	252	152	***Oct 23***		197	157	261
Aug 24	176	195	242	148	***Oct 24***		207	156	255
Aug 25	173	197	230	150	***Oct 25***		194	153	
Aug 26	171	241	219	154	***Oct 26***		189		
Aug 27	167	273	210	155	***Oct 27***		195		
Aug 28	171	262	205	149	***Oct 28***				
Aug 29	171	236	198	144	***Oct 29***				
Aug 30	174	220	192	137	***Oct 30***				
Aug 31	171	209	198	131	***Oct 31***				
Sept 1	164	199	184	131					
Sept 2	154	196	176	130					
Sept 3	153	205	170	129					
Sept 4	152	197	165	127					
Sept 5	141	187	164	127					
Sept 6	132	170	153	126					
Sept 7	136	161	142	125					
Sept 8	143	155	141	126					
Sept 9	144	144	138	126					
Sept 10	138	135	130	126					
Sept 11	136	133	134	126					
Sept 12	138	129	134	127					
Sept 13	150	143	134	126					
Sept 14	156	186	132	126					
Sept 15	151	185	125	129					
Sept 16	156	170	123	152					
Sept 17	197	174	124	153					
Sept 18	185	174	131	148					
Sept 19	166	178	129	148					
Sept 20	161	199	118	151					
Sept 21	155	213	113	155					
Sept 22	150	202	114	170					
Sept 23	142	198	121	178					
Sept 24	139	222	151	172					
Sept 25	140	237	182	173					
Sept 26	137	218	179	176					
Sept 27	135	206	163	179					
Sept 28	133	201	154	183					
Sept 29	138	195	149	181					
Sept 30	140	185	141	181					

Table B-3. Daily average streamflows for the upper East Boulder River gage.

Daily Average Streamflows in Cubic Feet Per Second (CFS) by year									
Day	**2003**	**2004**	**2005**	**2006**	**Day**	**2003**	**2004**	**2005**	**2006**
April 1		10.5			***June 1***	518	91.0	137.6	162
April 2		11.5			***June 2***	396	113.2	124.9	206
April 3		11.6			***June 3***	305	135.1	114.6	281
April 4		12.1			***June 4***	272	175.1	127.4	334
April 5		13.4			***June 5***	192	226.6	177.9	397
April 6		14.6			***June 6***	172	288.0	252.3	341
April 7		15.8	7.4		***June 7***	159	259.4	219.1	332
April 8		17.3	7.5		***June 8***	185	205.3	164.0	383
April 9		17.8	7.7		***June 9***	298	217.3	139.5	363
April 10		16.3	7.6		***June 10***	391	331.1	129.5	334
April 11		15.8	7.5		***June 11***	387	286.4	131.1	247
April 12		15.0	7.5		***June 12***	360	227.7	145.6	221
April 13		15.4	7.5		***June 13***	342	191.2	137.7	212
April 14		17.2	7.5		***June 14***	390	173.5	173.8	210
April 15		18.9	7.8		***June 15***	358	164.2	265.1	175
April 16		19.0	7.9		***June 16***	343	157.4	334.8	153
April 17		18.4	7.9		***June 17***	350	143.7	354.8	138
April 18		17.7	8.3		***June 18***	353	134.4	370.1	122
April 19		16.8	8.5		***June 19***	358	130.6	322.0	113
April 20		16.6	8.7		***June 20***	308	133.1	341.4	109
April 21		16.0	8.7		***June 21***	250	129.5	376.9	96
April 22		15.5	8.6		***June 22***	191	131.5	407.1	90
April 23		15.0	8.7		***June 23***	162	140.3	471.7	84
April 24		15.6	9.3		***June 24***	149	150.3	413.5	77
April 25		15.3	10.3	17	***June 25***	146	169.7	372.4	72
April 26		15.9	11.0	18	***June 26***	143	156.0	326.4	68
April 27		21.0	11.9	17	***June 27***	140	143.8	353.7	65
April 28		31.5	11.1	17	***June 28***	142	130.3	293.7	68
April 29		28.1	10.8	18	***June 29***	140	120.2	265.5	61
April 30		24.1	10.4	20	***June 30***	138	112.6	232.7	60
May 1		23.2	10.3	24	***July 1***	134	105.0	212.0	58
May 2		25.9	10.2	27	***July 2***	125	99.0	200.8	57
May 3		36.4	10.1	27	***July 3***	113	92.7	180.4	58
May 4		62.8	10.1	25	***July 4***	103	94.8	160.5	57
May 5		110.0	10.3	23	***July 5***	94.1	121.2	148.8	52
May 6		131.2	11.8	25	***July 6***	89.0	108.5	140.6	55
May 7		136.5	21.6	32	***July 7***	85.0	95.0	132.5	51
May 8		140.1	30.4	41	***July 8***	82.5	91.6	129.2	49
May 9		139.2	28.0	37	***July 9***	77.8	80.5	115.7	44
May 10		127.2	30.5	32	***July 10***	71.9	74.2	109.9	43
May 11		113.2	35.6	30	***July 11***	67.2	68.6	112.3	42
May 12		84.3	29.8	34	***July 12***	64.3	64.7	98.0	40
May 13		67.4	26.8	43	***July 13***	61.5	61.6	91.8	39
May 14		59.1	29.5	60	***July 14***	59.3	59.6	85.4	38
May 15		56.0	35.7	98	***July 15***	56.9	56.4	80.5	37
May 16		58.8	55.2	140	***July 16***	56.8	54.2	78.9	36
May 17		59.1	84.7	179	***July 17***	56.0	52.4	78.6	34
May 18		65.2	76.3	221	***July 18***	53.9	50.9	70.5	34
May 19		85.5	108.9	317	***July 19***	51.8	58.5	66.2	33
May 20		78.0	159.1	343	***July 20***	49.7	67.0	61.6	31
May 21	34.6	93.9	213.5	366	***July 21***	48.4	56.4	58.5	30
May 22	35.6	100.1	196.5	355	***July 22***	46.8	50.6	56.2	29
May 23	49.2	99.8	234.2	332	***July 23***	45.4	48.4	54.6	28
May 24	90.8	79.4	186.2	310	***July 24***	45.0	46.4	53.5	29
May 25	169	69.1	138.9	322	***July 25***	44.5	44.4	53.3	29
May 26	269	70.0	114.6	348	***July 26***	48.3	42.6	53.7	28
May 27	379	81.9	108.3	325	***July 27***	47.4	41.0	50.9	27
May 28	435	128.9	131.3	236	***July 28***	43.7	39.3	49.0	26
May 29	505	127.4	159.3	188	***July 29***	41.4	38.1	47.7	25
May 30	499	100.8	145.0	160	***July 30***	40.2	37.0	46.0	25
May 31	477	89.3	122.5	146	***July 31***	39.0	35.9	45.1	24

Table B-3. Daily average streamflows for the upper East Boulder River gage. (Continued)

Daily Average Streamflows in Cubic Feet Per Second (CFS) by year									
Day	***2003***	***2004***	***2005***	***2006***	***Day***	***2003***	***2004***	***2005***	***2006***
Aug 1	38.2	34.7	44.9	25	***Oct 1***	18.2	17.1	19.0	17
Aug 2	37.3	34.9	47.2	25	***Oct 2***	18.0	17.2	19.2	16
Aug 3	37.2	42.2	47.9	24	***Oct 3***	17.7	16.7	19.8	19
Aug 4	40.4	37.8	49.0	24	***Oct 4***	17.4	16.3	20.0	20
Aug 5	37.4	34.9	43.6	23	***Oct 5***	17.2	16.1	19.8	21
Aug 6	36.6	32.5	41.4	23	***Oct 6***	17.0	15.8	20.4	22
Aug 7	35.2	31.1	40.5	24	***Oct 7***	16.9	15.6	20.3	29
Aug 8	34.0	29.8	40.2	23	***Oct 8***		15.9	20.2	29
Aug 9	33.7	28.9	40.1	23	***Oct 9***		15.4	20.2	26
Aug 10	33.6	28.1	43.3	22	***Oct 10***		16.1	19.5	24
Aug 11	32.9	27.5	40.9	22	***Oct 11***		16.3	19.1	25
Aug 12	32.4	26.7	40.0	21	***Oct 12***		16.9	19.5	23
Aug 13	31.5	26.0	40.6	22	***Oct 13***		17.5	19.3	23
Aug 14	30.5	25.3	40.3	21	***Oct 14***		17.5	19.3	23
Aug 15	29.7	24.7	37.8	21	***Oct 15***		20.5	19.7	23
Aug 16	29.4	24.3	36.7	21	***Oct 16***		20.6	19.7	24
Aug 17	29.3	25.0	35.8	21	***Oct 17***		19.4	19.4	22
Aug 18	29.5	26.1	37.1	21	***Oct 18***		19.3	19.3	22
Aug 19	28.5	26.6	39.8	20	***Oct 19***		17.4	19.2	23
Aug 20	27.9	25.7	35.9	20	***Oct 20***		17.7	19.1	24
Aug 21	27.2	24.7	34.2	20	***Oct 21***		16.6	18.8	22
Aug 22	26.8	23.7	33.7	20	***Oct 22***		15.7	18.3	23
Aug 23	26.1	23.2	33.5	19	***Oct 23***		16.6	18.1	23
Aug 24	25.9	23.1	32.5	19	***Oct 24***		15.5	17.9	23
Aug 25	25.6	23.3	31.0	19	***Oct 25***		15.2	17.8	
Aug 26	25.3	27.1	30.6	19	***Oct 26***		16.0		
Aug 27	25.1	27.7	29.7	19	***Oct 27***				
Aug 28	24.8	26.2	29.3	19	***Oct 28***				
Aug 29	24.6	23.9	28.8	18	***Oct 29***				
Aug 30	24.6	22.6	28.0	18	***Oct 30***				
Aug 31	24.2	21.7	28.0	17	***Oct 31***				
Sept 1	23.8	21.1	27.7	17					
Sept 2	23.2	20.8	27.2	17					
Sept 3	22.8	20.7	26.3	17					
Sept 4	22.7	20.5	24.8	17					
Sept 5	22.4	20.2	24.4	16					
Sept 6	22.3	19.8	23.9	16					
Sept 7	22.2	19.6	23.4	16					
Sept 8	22.5	19.3	22.7	16					
Sept 9	22.5	18.9	22.3	16					
Sept 10	22.2	18.3	22.0	16					
Sept 11	21.9	18.1	21.7	15					
Sept 12	22.9	18.4	21.7	15					
Sept 13	22.6	20.4	21.8	15					
Sept 14	22.3	20.3	21.5	15					
Sept 15	22.1	20.0	21.1	15					
Sept 16	23.4	19.5	20.7	16					
Sept 17	26.0	18.8	20.7	16					
Sept 18	23.5	18.4	21.0	16					
Sept 19	22.6	18.3	20.6	16					
Sept 20	22.0	19.3	20.3	16					
Sept 21	21.4	19.0	20.0	16					
Sept 22	21.0	18.5	20.0	17					
Sept 23	20.5	18.6	20.4	17					
Sept 24	19.9	19.2	22.6	17					
Sept 25	19.7	18.4	22.3	17					
Sept 26	19.2	17.6	21.1	17					
Sept 27	18.7	17.1	20.5	17					
Sept 28	18.6	17.0	20.1	19					
Sept 29	18.4	16.8	19.7	19					
Sept 30	18.3	16.7	19.2	18					

Table B-4. Daily average streamflows for the lower East Boulder River gage.

Daily Average Streamflows in Cubic Feet Per Second (CFS) by year									
Day	***2003***	***2004***	***2005***	***2006***	***Day***	***2003***	***2004***	***2005***	***2006***
April 1		9.9			***June 1***	591	42.6	145.0	86.4
April 2		11.4			***June 2***	459	63.0	140.2	130.2
April 3		11.9			***June 3***	345	80.5	129.6	202.0
April 4		12.3			***June 4***	312	128.8	141.4	256.2
April 5		13.0			***June 5***	222	197.3	186.9	312.5
April 6		13.8			***June 6***	206	267.5	273.8	255.7
April 7		14.6	6.7		***June 7***	177	236.5	240.2	237.3
April 8		15.7	6.6		***June 8***	203	169.0	175.1	279.0
April 9		17.8	7.0		***June 9***	321	169.9	148.3	263.0
April 10		15.5	6.8		***June 10***	404	332.9	140.0	243.1
April 11		15.3	6.7		***June 11***	375	283.0	140.5	180.7
April 12		14.1	6.5		***June 12***	319	213.2	154.9	159.8
April 13		13.7	6.4		***June 13***	269	172.3	145.2	155.9
April 14		14.8	6.4		***June 14***	326	150.5	177.4	148.7
April 15		16.5	6.6		***June 15***	268	138.3	286.6	124.5
April 16		17.1	6.8		***June 16***	258	125.7	384.6	95.5
April 17		17.1	6.7		***June 17***	268	110.3	402.7	75.7
April 18		16.6	7.9		***June 18***	257	94.2	401.4	68.2
April 19		15.6	8.6		***June 19***	255	83.5	338.4	58.4
April 20		16.0	8.2		***June 20***		89.0	343.9	47.5
April 21		14.9	8.5		***June 21***		85.0	384.2	37.1
April 22		14.3	8.3		***June 22***		90.8	399.4	31.6
April 23		13.8	7.8		***June 23***		102.4	421.2	23.3
April 24		14.3	7.7		***June 24***		111.1	352.1	17.3
April 25		14.3	8.4	12.1	***June 25***	131	138.8	322.6	13.7
April 26		14.3	9.1	11.0	***June 26***	118	125.5	275.0	11.0
April 27		17.1	11.0	10.1	***June 27***	107	113.8	308.7	8.8
April 28		25.6	10.0	10.2	***June 28***	108	99.3	247.5	10.7
April 29		25.0	9.7	10.3	***June 29***	104	89.4	226.1	13.0
April 30		21.3	9.2	12.5	***June 30***	102	81.0	190.4	15.4
May 1		20.6	8.9	15.9	***July 1***	94.9	71.2	175.9	17.2
May 2		22.7	8.7	18.6	***July 2***	83.4	59.8	168.2	21.5
May 3		29.9	8.7	19.3	***July 3***	72.9	52.7	159.2	24.2
May 4		52.9	8.8	17.7	***July 4***	61.2	54.6	139.0	26.9
May 5		97.4	8.6	17.0	***July 5***	52.2	80.5	126.8	21.6
May 6		120.9	9.3	17.2	***July 6***	46.5	73.9	116.5	21.6
May 7		127.9	20.8	22.4	***July 7***	44.0	58.2	103.2	24.1
May 8		130.3	31.9	30.4	***July 8***	41.7	57.8	99.4	25.6
May 9		132.0	29.4	29.1	***July 9***	36.3	49.2	90.5	22.1
May 10		108.9	29.7	26.3	***July 10***	30.1	44.6	89.9	18.5
May 11		95.9	61.2	24.6	***July 11***	24.1	38.0	91.7	12.3
May 12		65.6	40.8	27.1	***July 12***	21.3	33.9	71.0	7.1
May 13		44.7	33.8	34.4	***July 13***	19.1	30.2	58.0	5.8
May 14		35.1	38.4	52.9	***July 14***	16.4	29.4	50.8	4.5
May 15		27.0	46.1	85.6	***July 15***	14.1	24.2	40.6	3.6
May 16		25.6	65.2	128.8	***July 16***	16.8	21.3	36.4	2.9
May 17		27.7	103.3	154.1	***July 17***	17.6	14.3	37.1	2.7
May 18		27.9	98.0	177.4	***July 18***	16.0	11.7	29.9	2.7
May 19		46.7	127.1	257.6	***July 19***	14.3	19.7	19.8	2.6
May 20		38.5	181.8	277.9	***July 20***	10.5	31.9	14.9	2.0
May 21	32.1	51.4	256.5	301.0	***July 21***	10.1	28.0	11.1	1.0
May 22	31.8	54.4	234.4	285.4	***July 22***	9.0	22.7	7.4	0.6
May 23	42.4	57.4	284.4	264.6	***July 23***	8.8	16.9	5.7	0.6
May 24	85.4	42.2	229.1	239.0	***July 24***	10.0	12.7	4.7	0.6
May 25	163	30.9	165.9	250.7	***July 25***	11.1	12.8	5.2	0.6
May 26	258	25.5	141.1	258.9	***July 26***	15.8	11.1	4.9	0.6
May 27	353	27.9	124.2	250.9	***July 27***	12.8	9.0	3.1	0.6
May 28	406	69.2	145.3	165.1	***July 28***	6.9	8.6	2.5	0.6
May 29	488	82.9	176.9	120.2	***July 29***	5.0	7.1	1.5	0.8
May 30	562	55.6	158.6	95.6	***July 30***	4.5	4.3	1.3	0.7
May 31	532	45.3	130.7	77.3	***July 31***	4.3	1.5	1.2	0.6

Table B-4. Daily average streamflows for the lower East Boulder River gage (Continued).

Daily Average Streamflows in Cubic Feet Per Second (CFS) by year									
Day	***2003***	***2004***	***2005***	***2006***	***Day***	***2003***	***2004***	***2005***	***2006***
Aug 1	4.1	0.0	1.1	0.6	***Oct 1***	1.5	11.3	7.8	0.7
Aug 2	3.5	0.0	1.2	0.6	***Oct 2***	6.0	13.0	8.5	0.7
Aug 3	2.7	0.6	1.2	0.6	***Oct 3***	6.5	13.4	9.8	0.6
Aug 4	3.3	0.1	1.0	0.6	***Oct 4***	6.9	12.0	10.2	0.7
Aug 5	2.2	0.0	0.8	0.6	***Oct 5***	6.5	14.2	12.0	0.8
Aug 6	1.1	0.0	0.8	0.5	***Oct 6***	7.3	13.6	11.2	1.3
Aug 7	0.9	0.0	1.0	0.5	***Oct 7***	8.4	14.8	11.6	8.7
Aug 8	1.0	0.0	1.2	0.5	***Oct 8***		16.0	11.1	13.3
Aug 9	0.9	0.0	1.2	0.5	***Oct 9***		15.9	12.2	11.8
Aug 10	0.9	0.0	1.6	0.5	***Oct 10***		14.6	11.6	11.8
Aug 11	0.8	0.0	1.5	0.5	***Oct 11***		13.1	11.6	13.8
Aug 12	0.9	0.0	1.2	0.5	***Oct 12***		13.0	11.6	11.3
Aug 13	0.7	0.0	1.2	0.6	***Oct 13***		14.6	12.1	10.1
Aug 14	0.7	0.0	1.3	0.6	***Oct 14***		13.9	14.7	10.7
Aug 15	0.9	0.0	1.2	0.6	***Oct 15***		17.5	15.3	10.3
Aug 16	0.7	0.0	1.0	0.6	***Oct 16***		18.2	15.5	18.3
Aug 17	1.1	0.0	1.0	0.6	***Oct 17***		17.4	15.4	20.3
Aug 18	1.3	0.0	1.1	0.6	***Oct 18***		16.0	15.4	20.0
Aug 19	0.8	0.0	1.4	0.6	***Oct 19***		15.1	15.3	20.8
Aug 20	0.8	0.0	1.2	0.5	***Oct 20***		14.4	15.4	26.0
Aug 21	0.9	0.0	1.1	0.5	***Oct 21***		11.3	15.4	21.3
Aug 22	1.0	0.0	0.9	0.5	***Oct 22***		10.5	14.9	21.6
Aug 23	0.9	0.0	0.9	0.5	***Oct 23***		10.8	14.7	21.9
Aug 24	1.0	0.0	0.9	0.5	***Oct 24***		10.6	14.9	21.7
Aug 25	1.0	0.0	0.9	0.5	***Oct 25***		10.9	14.4	
Aug 26	0.8	0.1	0.8	0.5	***Oct 26***		11.3		
Aug 27	0.9	4.3	0.9	0.5	***Oct 27***				
Aug 28	0.8	3.9	0.9	0.4	***Oct 28***				
Aug 29	0.6	4.8	0.7	0.0	***Oct 29***				
Aug 30	0.6	4.7	0.8	0.0	***Oct 30***				
Aug 31	0.5	4.6	0.8	0.0	***Oct 31***				
Sept 1	1.2	4.5	0.7	0.0					
Sept 2	1.1	5.7	0.9	0.0					
Sept 3	1.2	5.4	1.1	0.6					
Sept 4	1.3	5.1	2.2	0.6					
Sept 5	1.6	4.7	3.3	0.6					
Sept 6	1.2	4.1	2.9	0.7					
Sept 7	1.2	3.6	1.3	0.6					
Sept 8	1.1	2.8	1.3	0.6					
Sept 9	1.3	2.8	1.3	0.6					
Sept 10	1.7	4.1	1.4	0.6					
Sept 11	1.7	4.4	1.3	0.6					
Sept 12	1.9	5.0	0.9	0.6					
Sept 13	1.5	7.1	1.0	0.6					
Sept 14	1.0	8.2	1.4	0.6					
Sept 15	0.8	7.8	1.4	0.6					
Sept 16	1.3	6.3	1.2	0.6					
Sept 17	1.6	5.3	0.9	0.6					
Sept 18	1.4	5.2	1.6	0.6					
Sept 19	0.7	5.9	4.3	0.6					
Sept 20	0.6	6.8	3.0	0.7					
Sept 21	0.5	8.8	0.9	0.6					
Sept 22	0.4	12.9	1.0	0.6					
Sept 23	0.3	13.1	1.1	0.6					
Sept 24	0.2	13.3	3.2	0.6					
Sept 25	0.2	11.5	7.5	0.6					
Sept 26	0.1	10.8	6.7	0.6					
Sept 27	0.1	11.8	6.2	0.6					
Sept 28	0.1	11.9	6.7	0.6					
Sept 29	0.1	11.1	7.0	0.6					
Sept 30	0.2	10.5	6.5	0.7					

Table B-5. Daily average streamflows for the upper West Boulder River gage.

Daily Average Streamflows in Cubic Feet Per Second (CFS) by year									
Day	***2003***	***2004***	***2005***	***2006***	***Day***	***2003***	***2004***	***2005***	***2006***
April 1		54.8			***June 1***	1,480	191.2	340.6	324.9
April 2		51.7			***June 2***	1,036	227.1	304.7	437.3
April 3		46.2			***June 3***	744	312.9	294.2	705.9
April 4		54.0			***June 4***	649	510.7	323.4	874.1
April 5		66.0			***June 5***	484	676.0	399.5	1025.5
April 6		80.7			***June 6***	431	896.4	619.2	919.0
April 7		82.1	34.1		***June 7***	374	727.8	517.6	950.1
April 8		97.7	42.1		***June 8***	394	548.3	390.1	1198.2
April 9		93.1	38.8		***June 9***	706	538.2	325.0	1166.5
April 10		80.0	34.9		***June 10***	858	856.0	288.9	1006.2
April 11		73.6	33.6		***June 11***	831	852.6	285.3	782.9
April 12		71.8	34.6		***June 12***	763	593.1	313.7	807.0
April 13		84.7	39.1		***June 13***	715	507.0	291.3	875.9
April 14		103.6	49.8		***June 14***	836	469.3	314.4	835.5
April 15		109.6	42.0		***June 15***	755	458.3	553.4	661.7
April 16		95.5	41.2		***June 16***	713	408.5	797.2	540.9
April 17		90.9	48.7		***June 17***	793	351.2	914.5	541.5
April 18		86.3	60.4		***June 18***	813	309.4	922.5	506.1
April 19		78.4	52.5		***June 19***	849	297.2	746.3	483.5
April 20		77.0	47.0		***June 20***	784	344.8	811.8	472.4
April 21		72.6	44.0		***June 21***	634	343.9	978.5	427.9
April 22		67.8	44.3		***June 22***	408	418.6	1202.6	385.2
April 23		64.8	55.7		***June 23***		550.3	1284.2	390.8
April 24		70.8	70.9		***June 24***		687.3	1034.1	392.8
April 25		67.2	77.9	82.0	***June 25***		704.4	897.7	382.6
April 26		71.9	80.4	82.3	***June 26***	283	658.0	765.1	376.4
April 27		100.8	73.4	84.2	***June 27***	337	602.6	713.9	365.8
April 28		130.9	64.6	81.8	***June 28***	428	561.5	637.4	340.0
April 29		109.7	60.0	93.4	***June 29***	470	561.0	582.4	349.7
April 30		98.3	55.6	128.4	***June 30***	498	555.4	518.4	369.5
May 1		96.5	52.7	135.5	***July 1***	500	520.1	542.4	352.3
May 2		112.0	50.7	138.0	***July 2***	461	487.6	531.3	306.5
May 3		166.3	51.0	123.7	***July 3***	424	441.5	452.3	284.9
May 4		246.0	56.8	112.8	***July 4***	381	473.1	389.8	266.3
May 5		340.2	66.7	108.7	***July 5***	364	524.1	390.2	273.5
May 6		384.6	104.9	125.6	***July 6***	353	409.1	397.0	303.7
May 7		396.9	148.2	148.6	***July 7***	340	426.2	408.6	290.2
May 8		392.1	162.9	157.4	***July 8***	348	409.9	413.2	244.9
May 9		360.6	147.1	138.0	***July 9***	317	341.3	402.2	221.0
May 10		302.3	176.3	121.9	***July 10***	290	337.4	429.0	211.3
May 11		271.2	158.5	116.9	***July 11***	271	339.2	431.8	195.5
May 12		216.2	127.2	137.7	***July 12***	265	318.1	330.0	197.1
May 13		181.1	118.4	183.3	***July 13***	257	299.0	311.7	209.8
May 14		158.6	131.4	245.2	***July 14***	239	302.4	301.0	182.5
May 15		145.7	173.0	345.0	***July 15***	222	287.9	257.4	168.0
May 16		146.7	306.1	488.9	***July 16***	209	266.8	255.2	159.2
May 17		139.8	379.1	644.1	***July 17***	201	250.4	236.3	154.0
May 18		150.2	272.4	800.2	***July 18***	193	235.9	198.1	145.6
May 19		203.2	454.2	1032.7	***July 19***	183	272.4	182.7	138.9
May 20		181.0	588.7	1116.2	***July 20***	173	330.5	174.1	127.3
May 21		215.8	818.1	1138.1	***July 21***	168	243.7	163.4	122.0
May 22	188	234.3	635.0	1033.1	***July 22***	152	209.5	152.5	118.8
May 23	334	233.6	785.5	1006.3	***July 23***	144	181.3	153.9	114.5
May 24	570	198.9	606.2	895.1	***July 24***	146	163.3	155.0	115.8
May 25	864	173.6	413.0	845.8	***July 25***	147	153.7	148.0	113.6
May 26	1,038	166.9	341.6	850.3	***July 26***	183	146.8	141.9	104.8
May 27	1,120	193.3	328.6	727.7	***July 27***	180	141.6	122.9	99.9
May 28	1,219	296.7	396.5	539.9	***July 28***	140	134.9	115.6	95.5
May 29	1,426	327.6	466.1	411.7	***July 29***	125	126.1	110.7	92.2
May 30	1,434	239.9	393.4	338.6	***July 30***	115	120.2	108.6	89.0
May 31	1,396	206.3	318.6	308.1	***July 31***	109	116.3	105.0	85.5

Table B-5. Daily average streamflows for the upper West Boulder River gage (Continued).

Daily Average Streamflows in Cubic Feet Per Second (CFS) by year									
Day	***2003***	***2004***	***2005***	***2006***	***Day***	***2003***	***2004***	***2005***	***2006***
Aug 1	103	115.0	103.8	84.5	***Oct 1***	35.3	68.6	38.9	65.7
Aug 2	98.8	111.6	107.1	83.4	***Oct 2***	33.3	62.5	41.0	63.0
Aug 3	97.1	127.1	129.5	77.0	***Oct 3***	32.8	57.4	48.4	98.0
Aug 4	123	118.2	108.6	73.9	***Oct 4***	32.5	55.9	48.5	92.9
Aug 5	104	107.9	98.7	73.0	***Oct 5***	32.0	53.6	46.2	84.4
Aug 6	95.8	101.8	94.2	70.8	***Oct 6***	31.2	51.6	45.7	85.4
Aug 7	90.3	95.9	90.7	69.8	***Oct 7***		55.2	49.4	141.1
Aug 8	84.7	90.3	87.5	72.6	***Oct 8***		58.7	50.1	128.3
Aug 9	85.1	85.7	90.1	75.3	***Oct 9***		54.6	50.1	109.3
Aug 10	83.8	83.3	100.3	69.4	***Oct 10***		54.9	45.6	95.4
Aug 11	79.3	80.2	97.6	66.3	***Oct 11***		58.6	45.7	89.0
Aug 12	78.1	75.6	88.8	65.1	***Oct 12***		59.9	48.4	82.6
Aug 13	75.5	72.4	103.3	70.9	***Oct 13***		58.1	47.1	78.4
Aug 14	71.3	70.0	91.9	64.7	***Oct 14***		56.3	49.9	75.5
Aug 15	68.8	67.9	82.4	63.2	***Oct 15***		80.2	50.1	72.2
Aug 16	67.5	66.9	78.2	69.2	***Oct 16***		84.5	48.6	92.0
Aug 17	68.2	69.7	75.1	64.6	***Oct 17***		78.4	46.1	82.3
Aug 18	66.4	72.4	85.6	63.5	***Oct 18***		70.9	45.1	73.7
Aug 19	62.0	74.8	85.3	60.3	***Oct 19***		65.0	44.1	75.1
Aug 20	59.9	73.2	76.2	56.5	***Oct 20***		62.4	49.5	83.6
Aug 21	58.1	67.6	71.7	54.5	***Oct 21***		60.6	46.6	78.7
Aug 22	57.0	66.0	69.9	53.1	***Oct 22***		58.0	43.0	72.7
Aug 23	55.3	72.7	69.6	52.8	***Oct 23***		57.2	41.3	71.0
Aug 24	53.6	69.3	67.3	52.5	***Oct 24***		54.4	40.4	70.1
Aug 25	54.2	88.2	63.0	52.5	***Oct 25***		53.9	39.0	
Aug 26	51.3	103.9	62.5	58.2	***Oct 26***		52.2	38.9	
Aug 27	50.8	104.4	60.8	55.1	***Oct 27***				
Aug 28	54.0	91.2	58.6	52.9	***Oct 28***				
Aug 29	51.3	80.0	57.4	51.2	***Oct 29***				
Aug 30	51.0	73.4	57.6	47.4	***Oct 30***				
Aug 31	48.8	67.7	60.3	46.6	***Oct 31***				
Sept 1	47.3	64.6	56.1	46.7					
Sept 2	45.1	73.2	52.6	46.2					
Sept 3	43.5	75.4	50.7	45.6					
Sept 4	42.4	66.9	49.2	45.1					
Sept 5	41.7	62.6	48.5	44.3					
Sept 6	42.2	59.0	47.7	43.7					
Sept 7	46.9	56.3	46.4	43.5					
Sept 8	48.9	53.9	45.7	43.4					
Sept 9	47.2	51.4	44.2	43.5					
Sept 10	43.4	50.7	43.5	43.7					
Sept 11	44.6	49.4	43.7	42.2					
Sept 12	45.0	49.2	43.4	40.7					
Sept 13	49.4	80.0	43.5	39.0					
Sept 14	46.6	75.1	42.2	37.9					
Sept 15	44.4	72.6	40.5	41.2					
Sept 16	48.3	78.4	40.0	55.0					
Sept 17	65.2	75.5	41.1	51.8					
Sept 18	50.8	73.3	44.1	50.1					
Sept 19	47.7	72.8	41.1	53.8					
Sept 20	46.8	83.8	38.2	53.6					
Sept 21	43.4	73.6	36.3	59.8					
Sept 22	41.7	67.4	36.1	64.4					
Sept 23	40.9	76.4	39.8	59.7					
Sept 24	39.9	100.6	52.7	57.0					
Sept 25	39.1	85.2	56.9	59.0					
Sept 26	36.9	75.7	48.6	62.9					
Sept 27	35.8	70.4	46.0	66.2					
Sept 28	35.7	67.3	44.1	68.8					
Sept 29	35.5	62.6	41.7	71.7					
Sept 30	35.6	61.7	40.5	68.8					

Table B-6. Daily average streamflows for the lower West Boulder River gage.

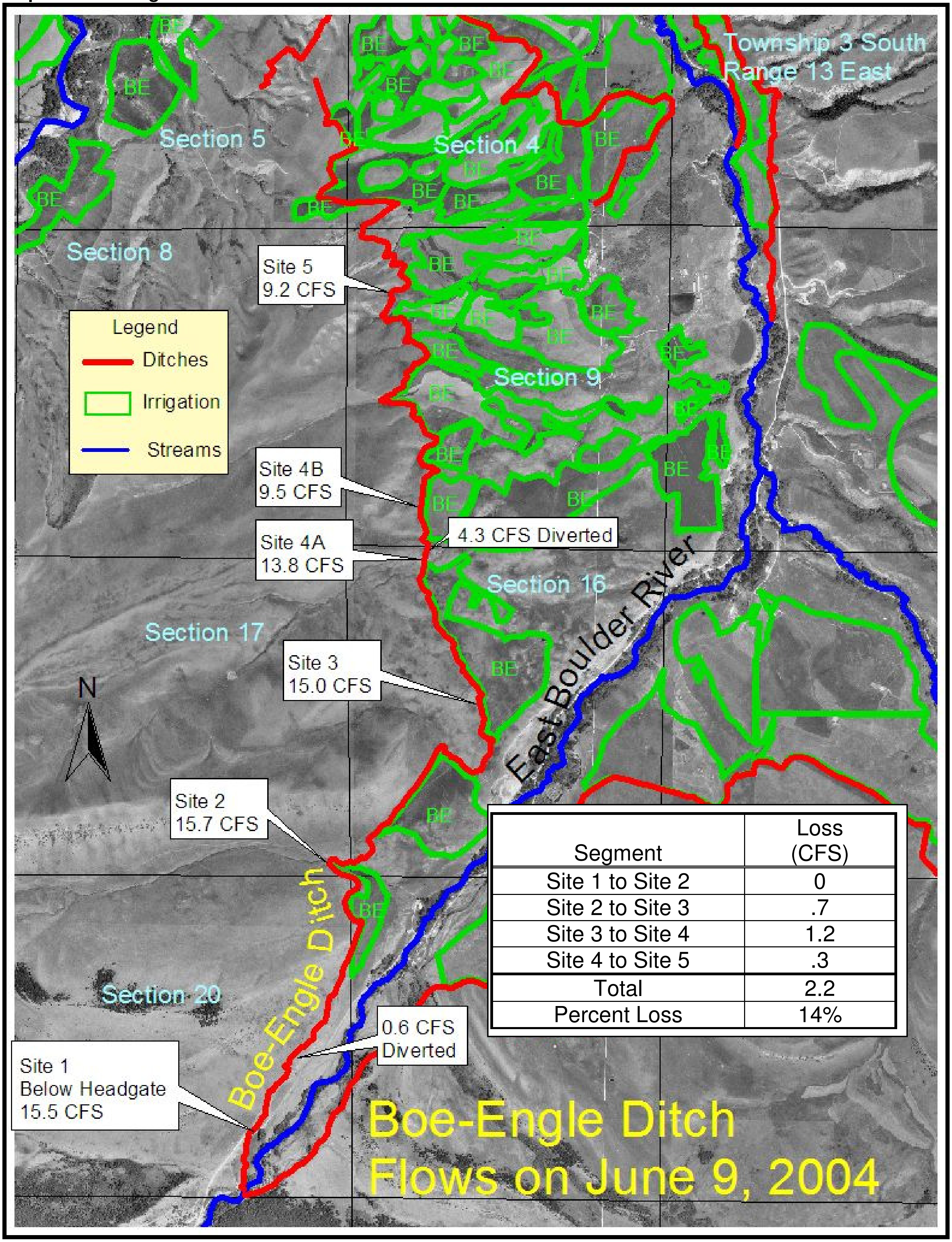
Daily Average Streamflows in Cubic Feet Per Second (CFS) by year									
Day	***2003***	***2004***	***2005***	***2006***	***Day***	***2003***	***2004***	***2005***	***2006***
April 1		59.6			***June 1***	819	148.9	337.2	284.1
April 2		62.6			***June 2***	813	165.1	309.2	350.6
April 3		57.9			***June 3***	699	221.3	276.9	562.2
April 4		59.7			***June 4***	616	434.6	295.3	786.0
April 5		68.0			***June 5***	469	609.5	348.6	976.5
April 6		80.1			***June 6***	442	780.0	519.2	897.3
April 7		83.6	42.9		***June 7***	364	711.5	498.9	881.4
April 8		94.3	46.0		***June 8***	341	556.3	380.6	1139.5
April 9		97.4	46.3		***June 9***	587	459.0	311.4	1135.7
April 10		84.8	43.4		***June 10***	762	772.9	268.2	1028.3
April 11		80.7	42.1		***June 11***	768		259.9	815.0
April 12		76.9	43.3		***June 12***	734		286.8	773.8
April 13		82.4	43.7		***June 13***	712		275.4	872.2
April 14		94.9	48.8		***June 14***	768		279.1	863.7
April 15		103.4	47.4		***June 15***	760		441.6	693.9
April 16		95.5	46.6		***June 16***	691		708.6	540.7
April 17		90.2	48.3		***June 17***	769		816.3	530.6
April 18		88.4	60.2		***June 18***	785		871.0	504.2
April 19		82.6	58.4		***June 19***	805		706.5	470.2
April 20		80.3	52.7		***June 20***	791		706.3	473.0
April 21		76.9	49.7		***June 21***	741		899.6	434.3
April 22		72.8	49.1		***June 22***	543		1070.5	381.8
April 23		69.4	54.8		***June 23***	402		1158.4	385.9
April 24		72.2	66.0		***June 24***	341		1017.7	394.5
April 25		70.8	74.8	87.6	***June 25***	292		883.3	382.1
April 26		70.2	77.8	82.5	***June 26***	256		786.3	374.2
April 27		83.5	76.6	80.9	***June 27***	301		738.5	359.1
April 28		111.6	65.1	78.6	***June 28***	391		660.7	332.4
April 29		104.1	60.0	84.0	***June 29***	422		638.2	343.7
April 30		94.0	58.3	116.6	***June 30***	433		604.1	370.8
May 1		89.9	55.9	133.8	***July 1***	448		606.1	366.3
May 2		94.4	53.8	137.3	***July 2***	408		569.7	317.1
May 3		115.6	53.6	125.7	***July 3***	379		502.8	297.5
May 4		173.2	54.3	113.7	***July 4***	329		423.5	273.0
May 5		264.2	56.6	105.3	***July 5***	307		413.8	251.1
May 6		321.7	80.1	116.3	***July 6***	292	391.0	415.7	300.5
May 7		315.2	129.8	140.5	***July 7***	273	418.3	431.2	275.2
May 8		319.7	148.3	158.1	***July 8***	268	431.0	431.7	237.9
May 9		294.2	140.4	143.7	***July 9***	251	350.0	427.4	197.7
May 10		221.7	176.0	125.9	***July 10***	220	332.4	420.8	191.5
May 11		192.4	221.1	113.7	***July 11***	199	337.8	484.4	172.7
May 12		161.7	169.2	115.0	***July 12***	190	318.9	357.9	166.9
May 13		138.6	147.5	149.7	***July 13***	183	285.0	311.7	181.7
May 14		107.2	159.8	213.7	***July 14***	154	279.5	306.3	156.0
May 15		92.5	186.3	311.0	***July 15***		280.6	250.7	137.2
May 16		90.8	301.2	427.4	***July 16***	137	253.7	224.7	118.9
May 17		89.9	413.0	563.1	***July 17***	134	233.6	207.8	105.6
May 18		88.8	313.2	689.8	***July 18***	128	209.4	160.1	97.2
May 19		124.4	399.9	934.8	***July 19***	123	229.2	141.1	94.2
May 20	120	114.1	582.1	1052.4	***July 20***	113	310.8	131.7	84.1
May 21	118	145.9	786.4	1086.7	***July 21***	110	219.6	120.5	86.5
May 22	146	164.6	615.3	996.0	***July 22***	104	166.1	107.8	86.1
May 23	309	177.4	772.9	947.6	***July 23***	94.1	142.8	111.3	82.5
May 24	550	152.6	642.5	860.0	***July 24***	94.0	115.9	108.2	81.0
May 25	755	132.6	458.0	776.3	***July 25***	95.7	100.1	99.4	78.4
May 26	816	127.8	377.4	821.6	***July 26***	118	94.2	103.2	66.7
May 27	819	133.6	343.9	702.0	***July 27***	122	87.9	88.0	67.2
May 28	819	213.8	390.9	528.9	***July 28***	96.0	79.3	80.6	66.6
May 29	819	300.9	475.4	413.0	***July 29***	94.2	75.3	74.7	63.1
May 30	819	213.5	422.9	336.3	***July 30***	87.2	68.7	70.7	58.1
May 31	819	173.7	332.6	291.8	***July 31***	79.3	66.1	68.7	55.0

Table B-6. Daily average streamflows for the lower West Boulder River gage (Continued).

Daily Average Streamflows in Cubic Feet Per Second (CFS) by year									
Day	***2003***	***2004***	***2005***	***2006***	***Day***	***2003***	***2004***	***2005***	***2006***
Aug 1	72.0	67.1	73.8	54.8	***Oct 1***	44.2	69.8	40.3	63.4
Aug 2	67.9	67.5	82.0	56.6	***Oct 2***	41.9	66.2	40.3	61.0
Aug 3	63.9	77.8	103.1	47.2	***Oct 3***	37.6	62.4	47.5	85.9
Aug 4	72.8	80.2	87.0	39.4	***Oct 4***	32.3	60.0	51.4	95.8
Aug 5	65.7	77.4	73.4	39.2	***Oct 5***	29.1	58.3	52.7	85.1
Aug 6	58.1	75.5	67.4	39.0	***Oct 6***	30.1	55.3	52.8	83.9
Aug 7	54.4	71.1	63.8	38.6	***Oct 7***	29.9	53.9	54.2	120.4
Aug 8	50.5	66.5	62.1	38.4	***Oct 8***		63.0	55.3	137.9
Aug 9	49.7	64.4	62.7	38.4	***Oct 9***		57.4	57.8	115.1
Aug 10	49.7	61.9	72.5	38.4	***Oct 10***		59.8	53.4	100.9
Aug 11	48.9	58.1	71.5	38.3	***Oct 11***		64.6	49.8	98.6
Aug 12	48.4	54.8	67.1	38.3	***Oct 12***		66.4	48.1	89.8
Aug 13	48.5	52.8	82.4	38.5	***Oct 13***		66.8	48.3	85.2
Aug 14	46.0	49.9	78.8	38.9	***Oct 14***		64.5	49.2	81.5
Aug 15	43.7	48.0	68.9	38.8	***Oct 15***		74.4	50.6	79.7
Aug 16	45.0	46.3	64.0	40.7	***Oct 16***		84.0	50.1	103.0
Aug 17	47.0	49.9	57.3	41.3	***Oct 17***		84.5	48.9	98.4
Aug 18	47.7	54.0	62.8	40.3	***Oct 18***		76.6	46.9	84.4
Aug 19	44.7	57.1	76.2	39.1	***Oct 19***		71.2	46.1	86.1
Aug 20	41.3	54.9	72.1	38.2	***Oct 20***		67.1	50.3	98.3
Aug 21	39.5	52.0	67.5	38.0	***Oct 21***		65.0	51.8	92.5
Aug 22	46.7	52.0	63.3	37.7	***Oct 22***		62.3	47.4	84.4
Aug 23	53.1	55.1	62.1	37.7	***Oct 23***		62.3	46.6	82.6
Aug 24	53.5	53.9	60.5	37.8	***Oct 24***		60.6	45.8	82.3
Aug 25	54.4	62.4	58.4	38.0	***Oct 25***		59.0	45.1	
Aug 26	50.8	86.3	56.9	38.4	***Oct 26***		63.6		
Aug 27	46.9	93.1	54.9	38.2	***Oct 27***				
Aug 28	49.3	91.4	54.6	38.1	***Oct 28***				
Aug 29	47.4	81.5	53.0	38.0	***Oct 29***				
Aug 30	48.2	74.6	52.5	37.8	***Oct 30***				
Aug 31	44.8	69.4	54.6	37.8	***Oct 31***				
Sept 1	39.4	65.3	45.8	37.6					
Sept 2	36.5	67.8	43.3	37.5					
Sept 3	38.0	77.1	42.3	37.4					
Sept 4	38.6	69.0	41.6	37.7					
Sept 5	32.3	64.1	41.6	38.2					
Sept 6	30.3	61.0	41.6	38.3					
Sept 7	35.6	58.6	41.4	38.2					
Sept 8	37.6	54.7	41.4	38.1					
Sept 9	35.4	46.6	41.1	38.1					
Sept 10	26.8	41.3	40.8	38.4					
Sept 11	29.1	38.9	41.3	38.9					
Sept 12	31.1	37.9	40.9	39.2					
Sept 13	39.8	62.5	40.4	38.6					
Sept 14	46.3	70.0	40.4	37.3					
Sept 15	43.3	71.3	40.3	39.8					
Sept 16	46.5	63.1	39.9	47.1					
Sept 17	67.4	67.8	39.7	45.3					
Sept 18	57.5	69.8	39.8	44.2					
Sept 19	53.3	71.0	39.6	45.3					
Sept 20	54.5	80.4	39.6	45.5					
Sept 21	52.7	76.6	39.6	49.3					
Sept 22	50.8	70.7	39.6	60.3					
Sept 23	47.7	69.8	39.6	62.7					
Sept 24	45.9	93.3	41.2	59.3					
Sept 25	46.1	85.2	46.0	58.5					
Sept 26	45.7	77.1	42.1	59.8					
Sept 27	44.8	72.3	41.0	61.4					
Sept 28	44.9	69.5	40.5	66.6					
Sept 29	44.8	66.1	40.4	65.5					
Sept 30	44.6	63.8	40.4	65.0					

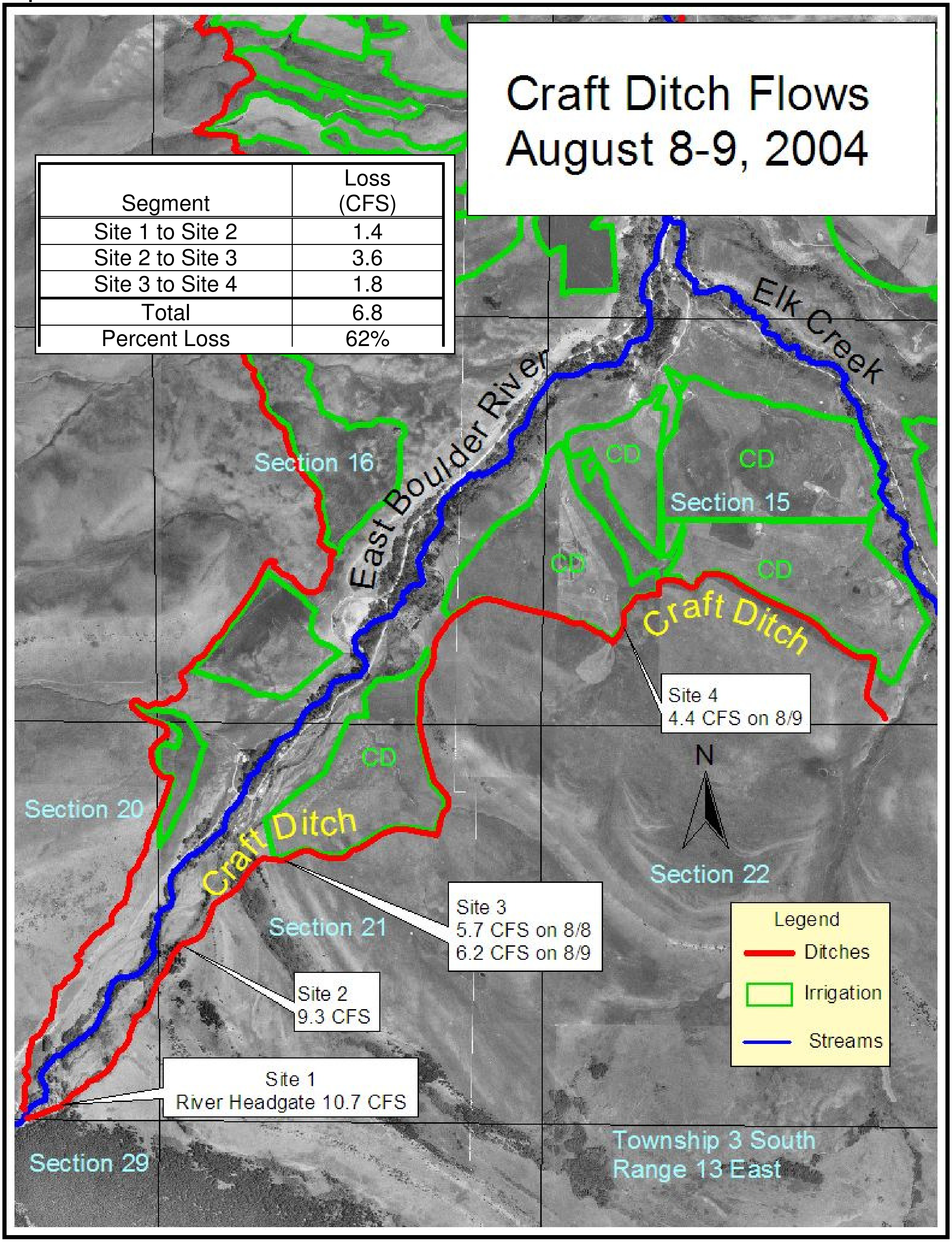
Appendix C: Ditch Efficiency Assessment Summaries.

Map C-1. Boe-Engle Ditch Flows.



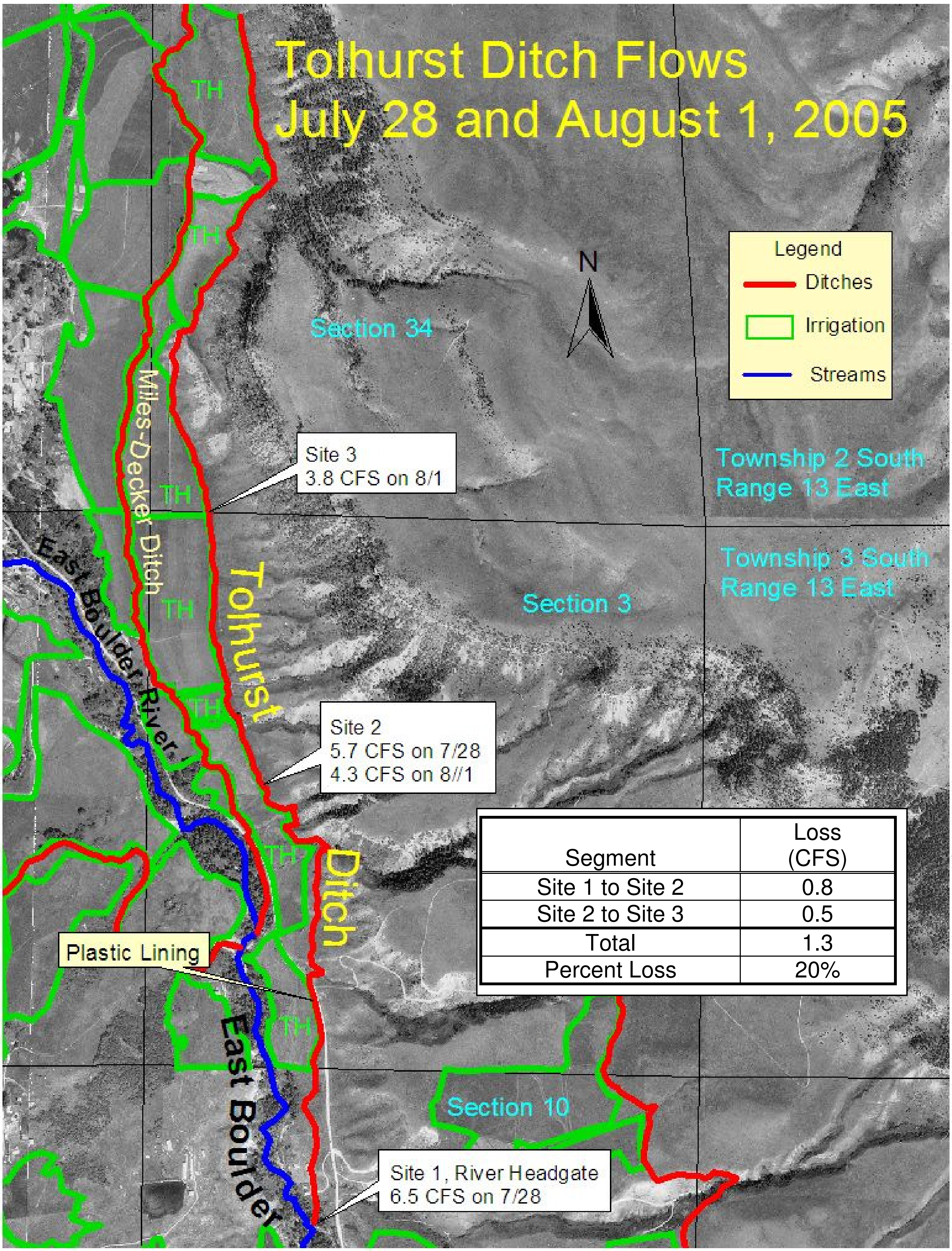
Segment	Loss (CFS)
Site 1 to Site 2	0
Site 2 to Site 3	.7
Site 3 to Site 4	1.2
Site 4 to Site 5	.3
Total	2.2
Percent Loss	14%

Map C-2. Craft Ditch Flows.



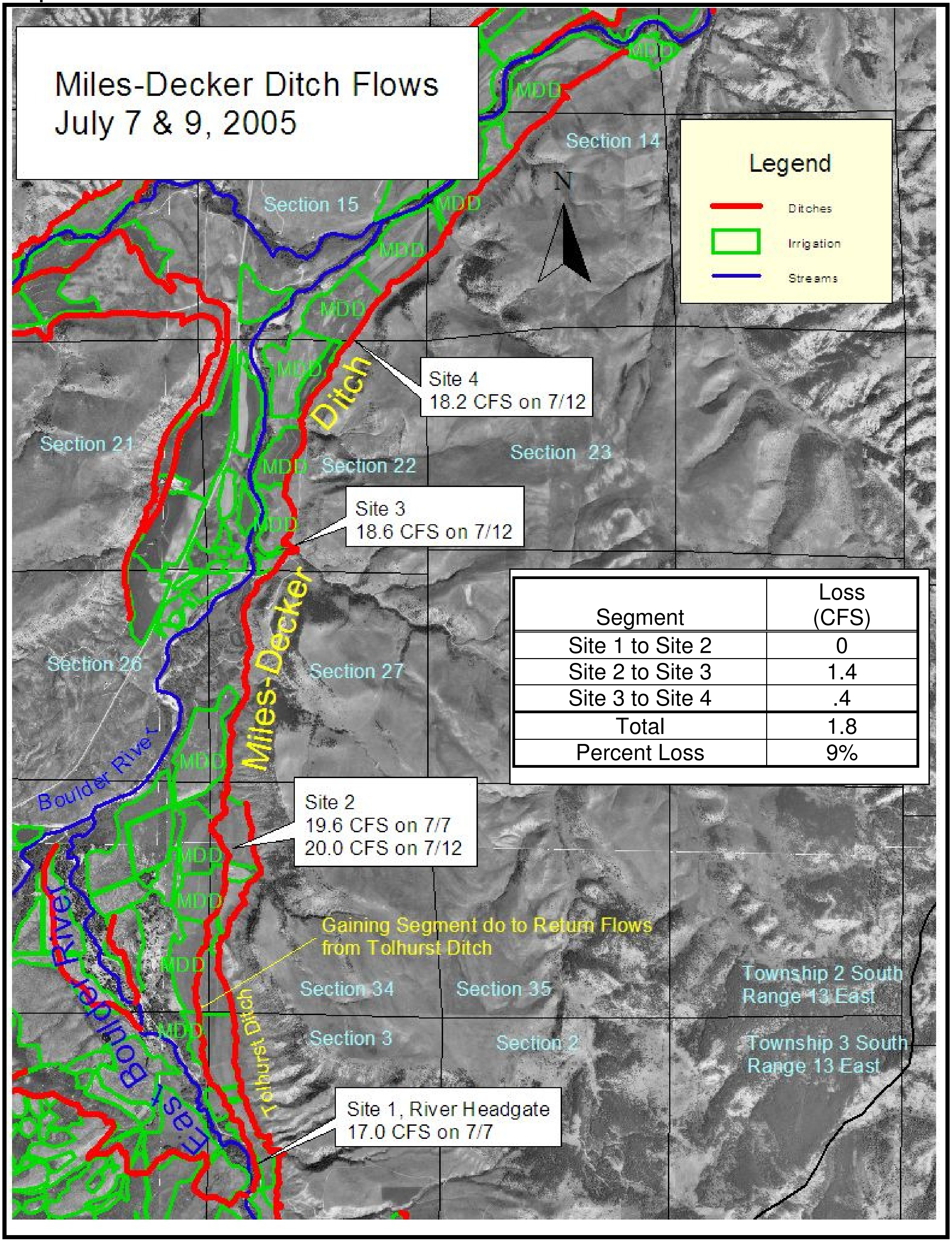
Segment	Loss (CFS)
Site 1 to Site 2	1.4
Site 2 to Site 3	3.6
Site 3 to Site 4	1.8
Total	6.8
Percent Loss	62%

Map C-3. Tolhurst Ditch Flows.



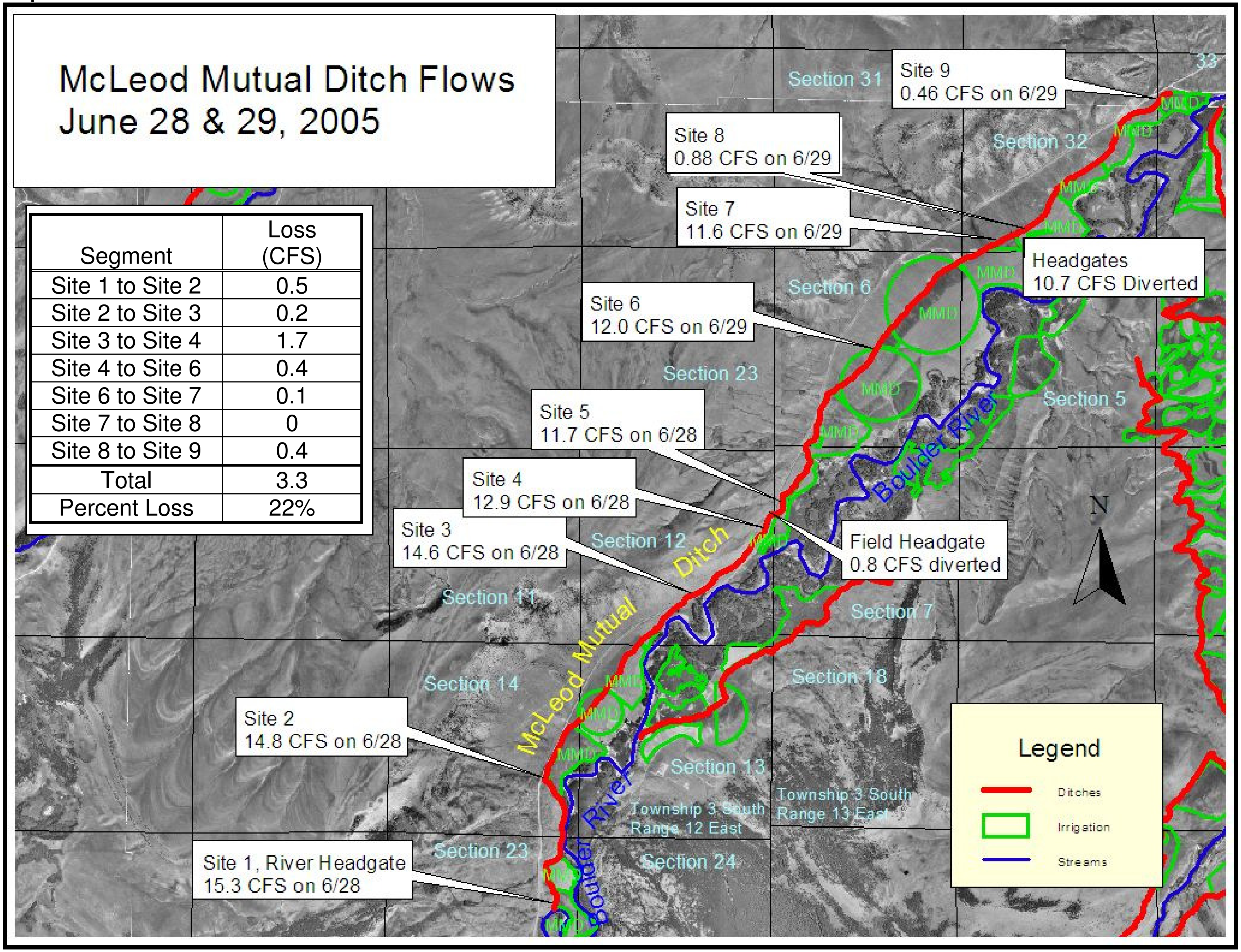
Segment	Loss (CFS)
Site 1 to Site 2	0.8
Site 2 to Site 3	0.5
Total	1.3
Percent Loss	20%

Map C-4. Miles-Decker Ditch Flows.



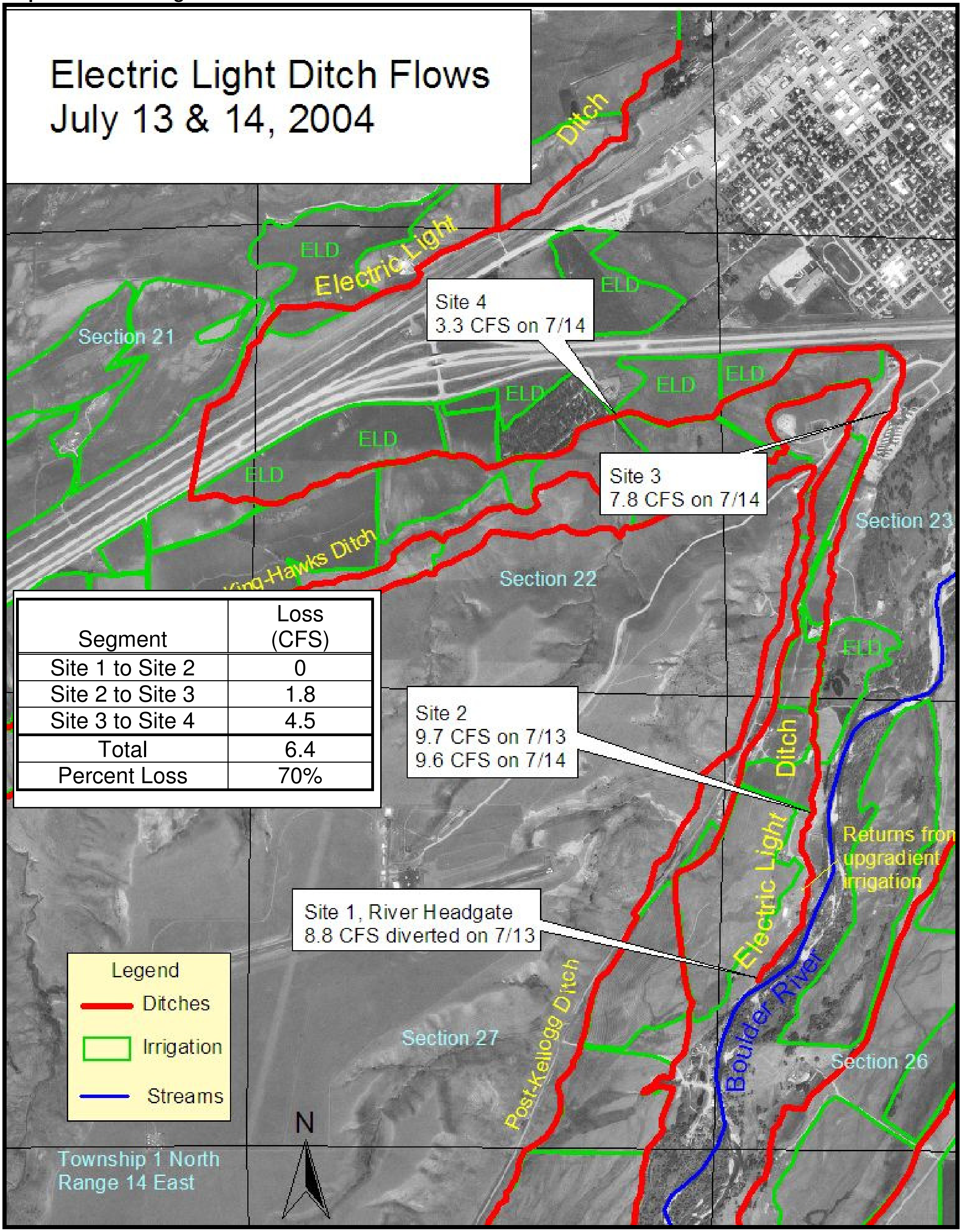
Segment	Loss (CFS)
Site 1 to Site 2	0
Site 2 to Site 3	1.4
Site 3 to Site 4	.4
Total	1.8
Percent Loss	9%

Map C-5. McLeod Mutual Ditch Flows.



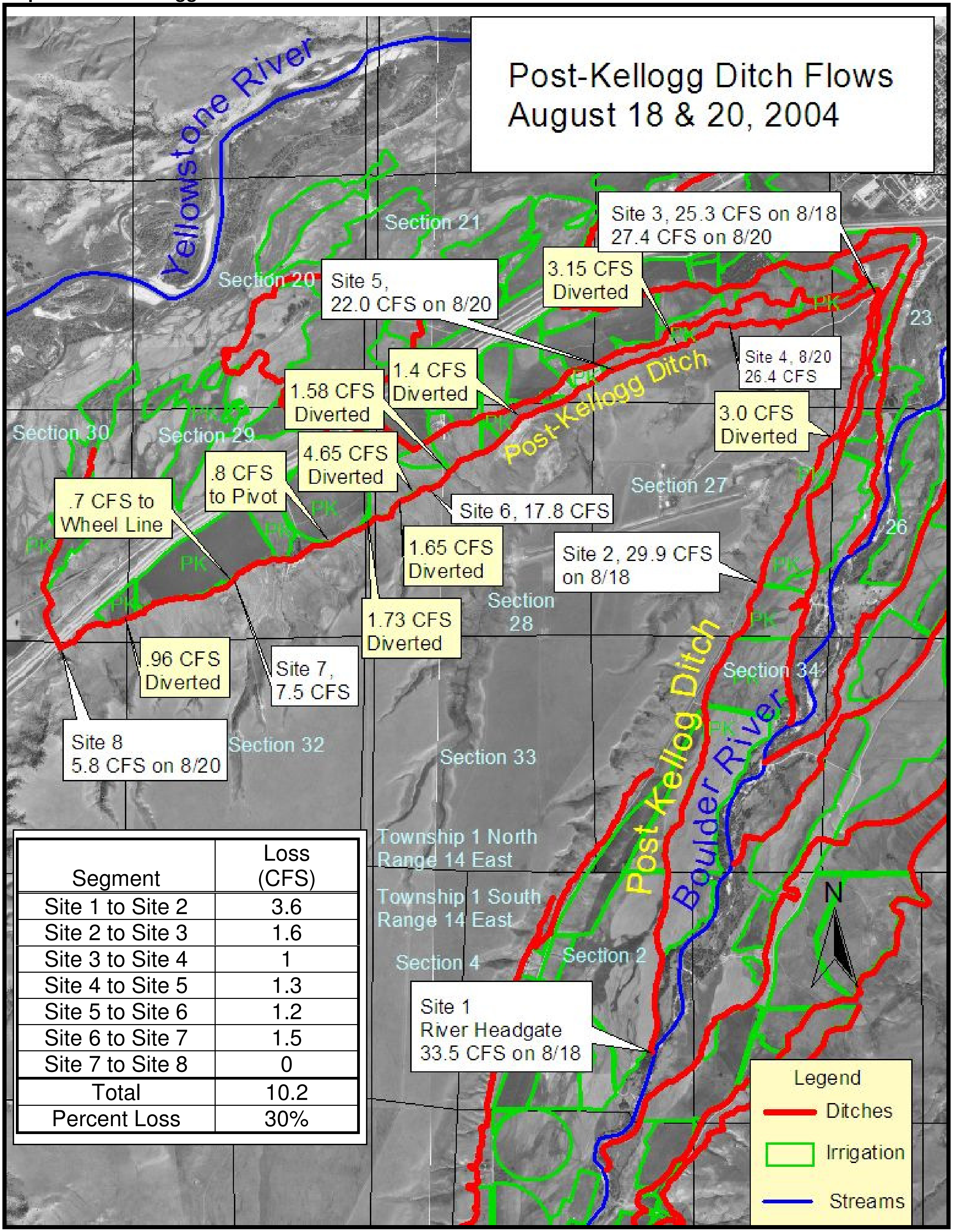
Segment	Loss (CFS)
Site 1 to Site 2	0.5
Site 2 to Site 3	0.2
Site 3 to Site 4	1.7
Site 4 to Site 6	0.4
Site 6 to Site 7	0.1
Site 7 to Site 8	0
Site 8 to Site 9	0.4
Total	3.3
Percent Loss	22%

Map C-6. Electric Light Ditch Flows.



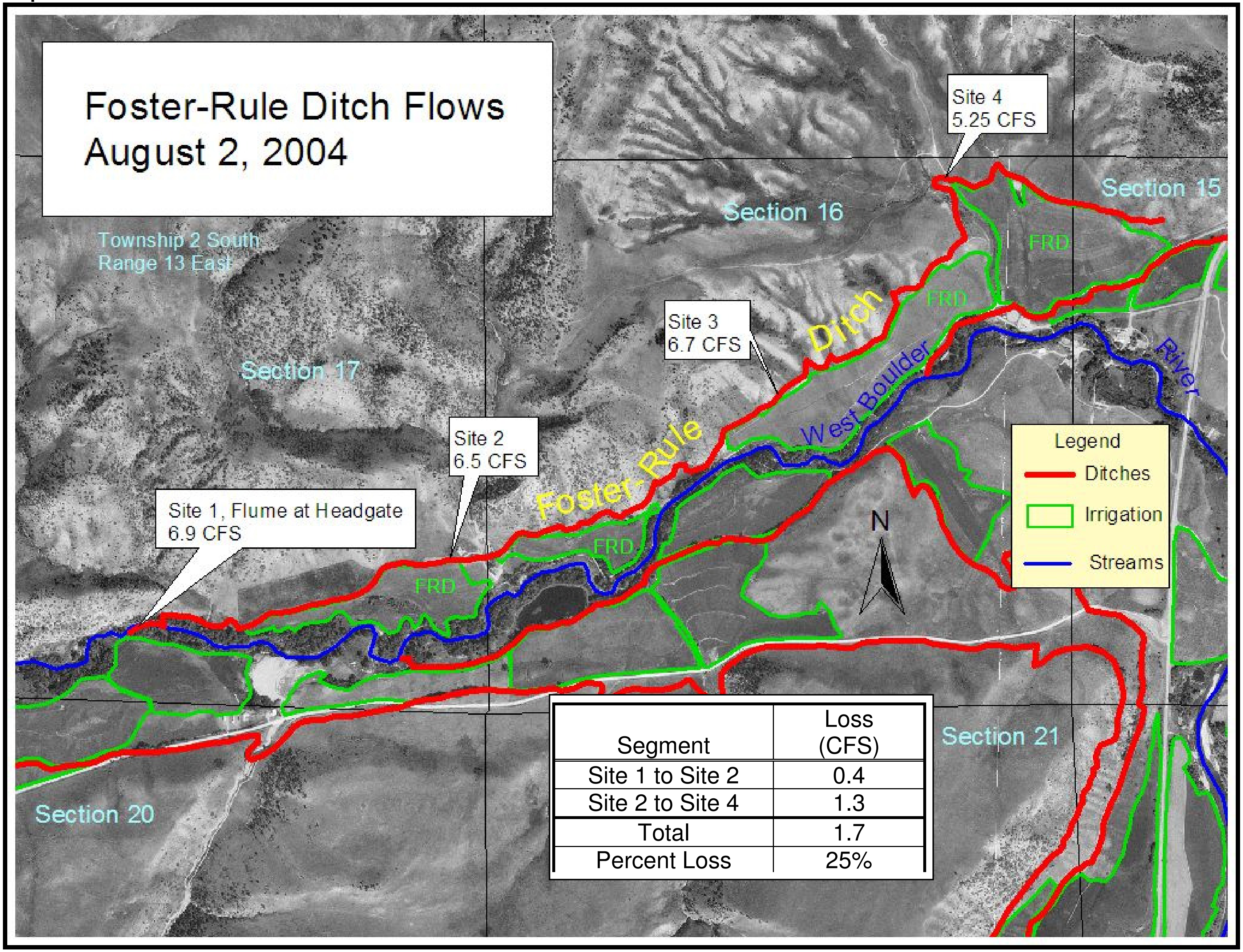
Segment	Loss (CFS)
Site 1 to Site 2	0
Site 2 to Site 3	1.8
Site 3 to Site 4	4.5
Total	6.4
Percent Loss	70%

Map C-7. Post-Kellogg Ditch Flows.



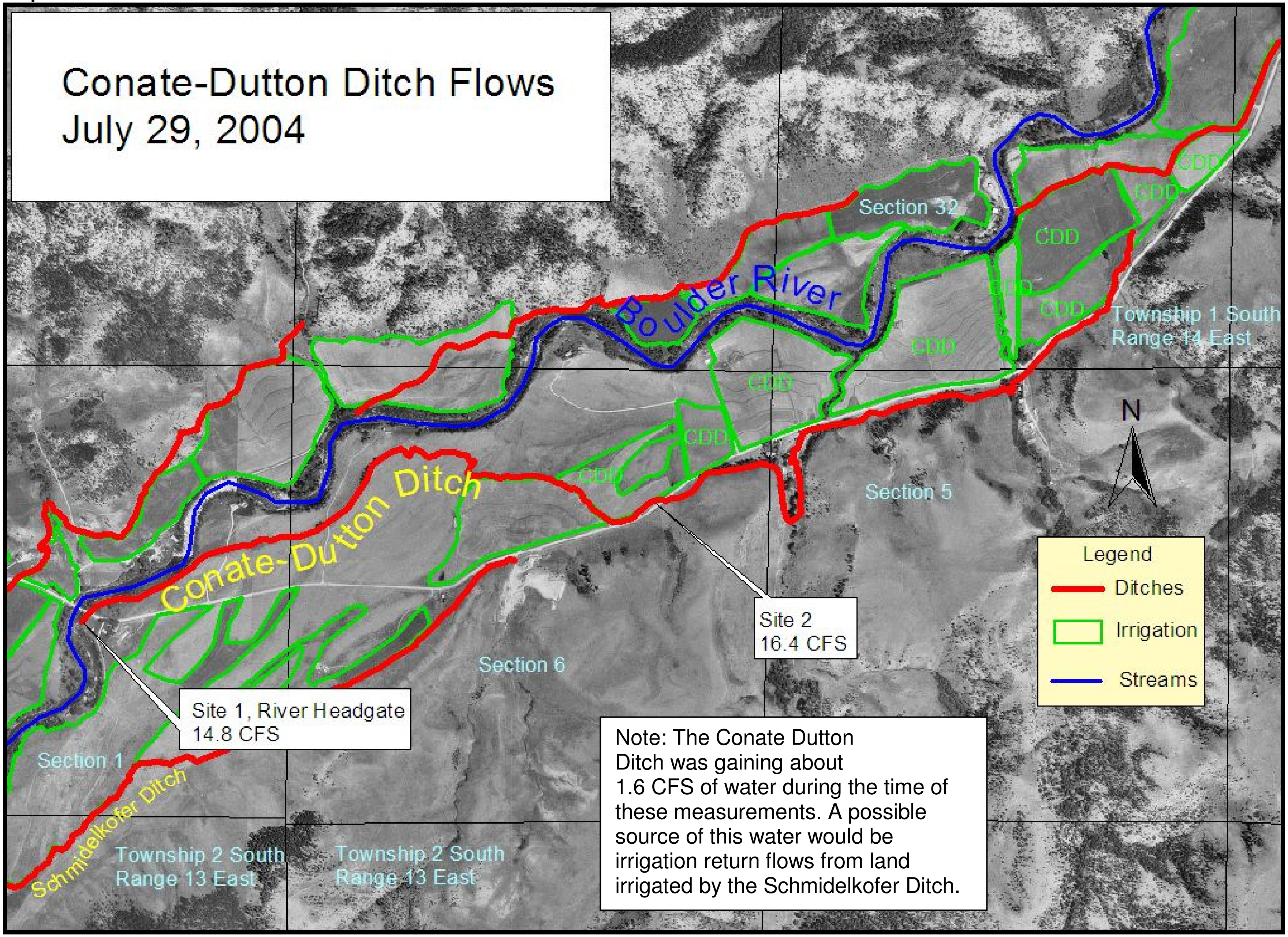
Segment	Loss (CFS)
Site 1 to Site 2	3.6
Site 2 to Site 3	1.6
Site 3 to Site 4	1
Site 4 to Site 5	1.3
Site 5 to Site 6	1.2
Site 6 to Site 7	1.5
Site 7 to Site 8	0
Total	10.2
Percent Loss	30%

Map C-8. Foster-Rule Ditch Flows.

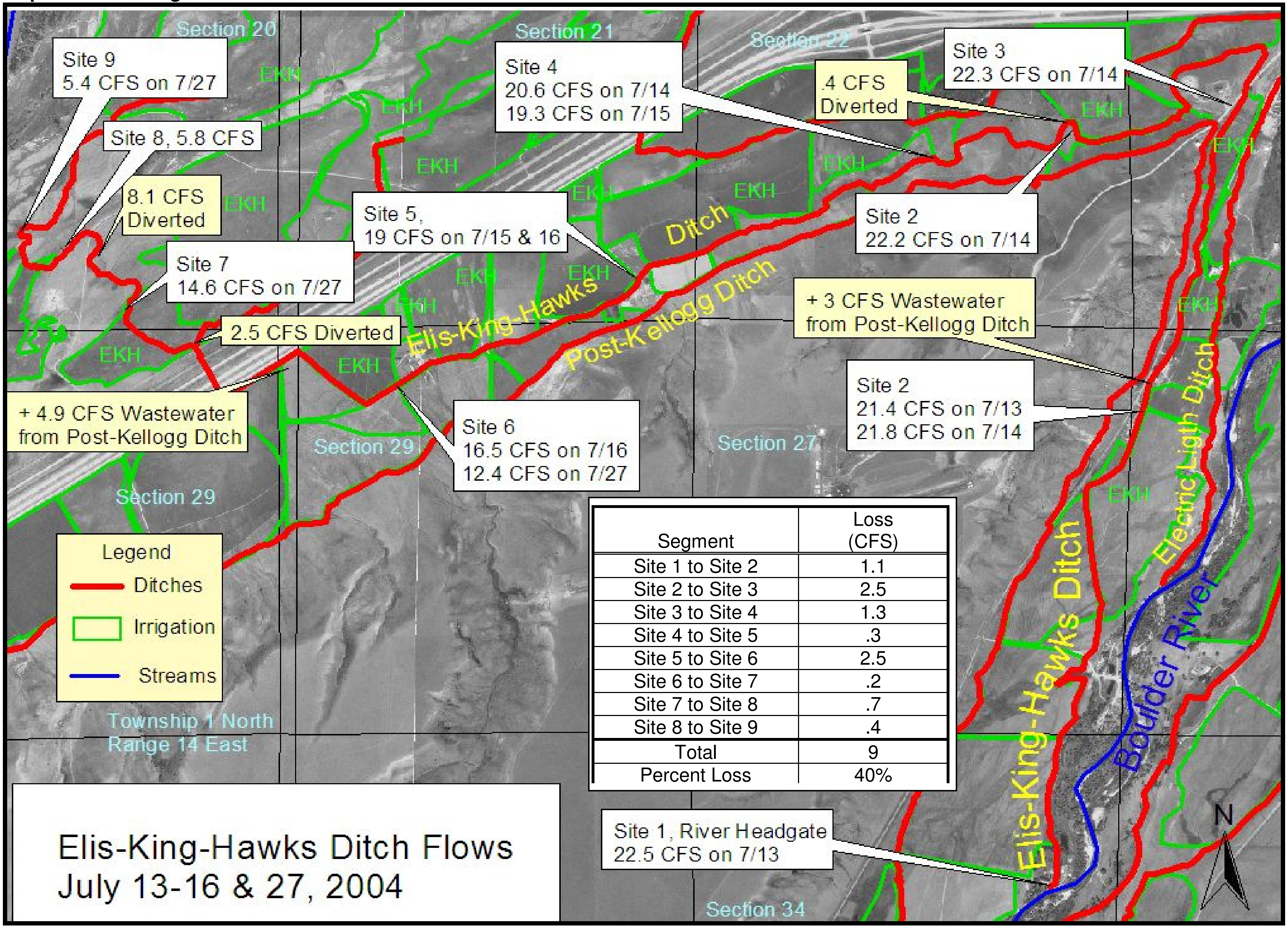


Segment	Loss (CFS)
Site 1 to Site 2	0.4
Site 2 to Site 4	1.3
Total	1.7
Percent Loss	25%

Map C-9. Conate-Dutton Ditch Flows.

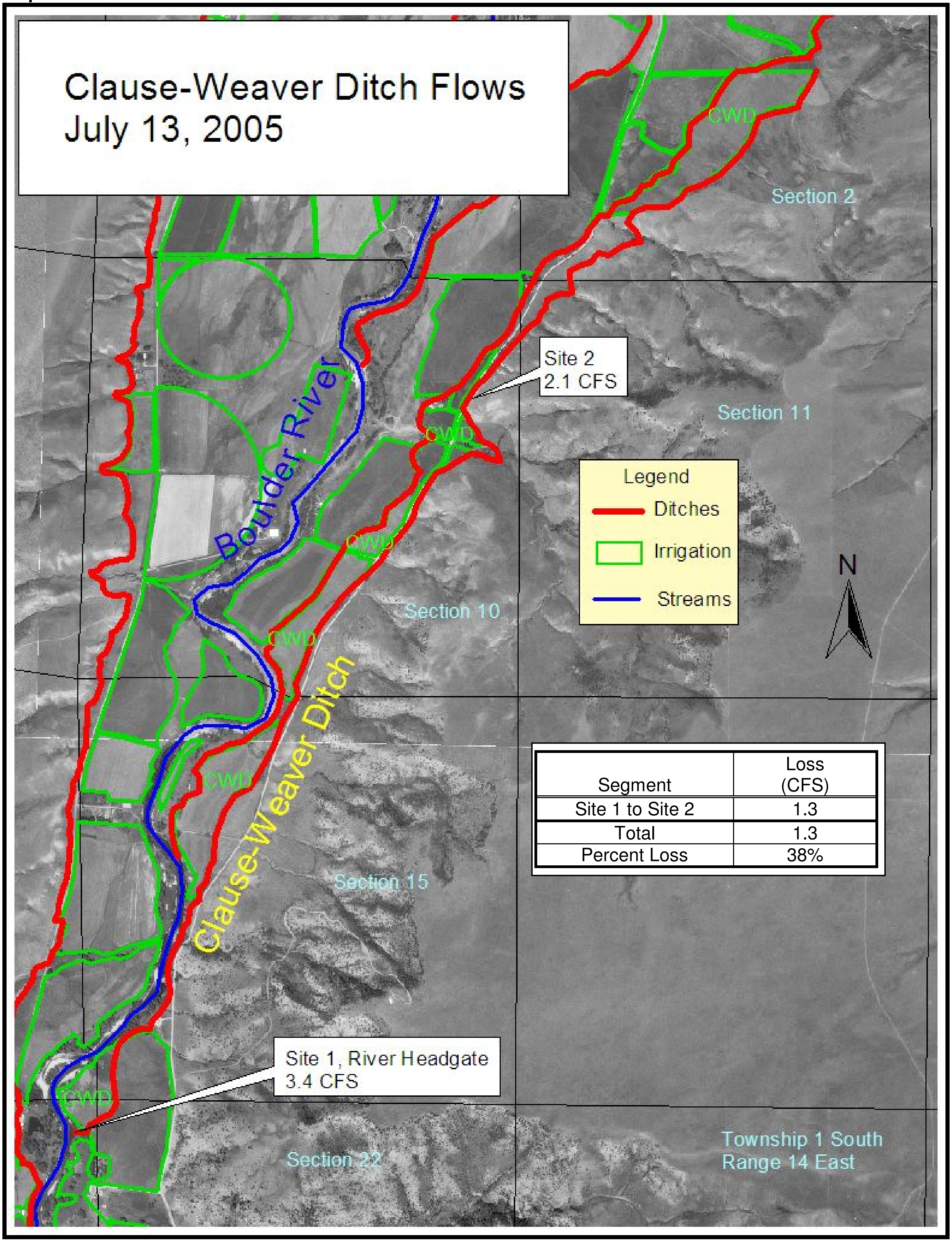


Map C-10. Elis-King-Hawks Ditch Flows.



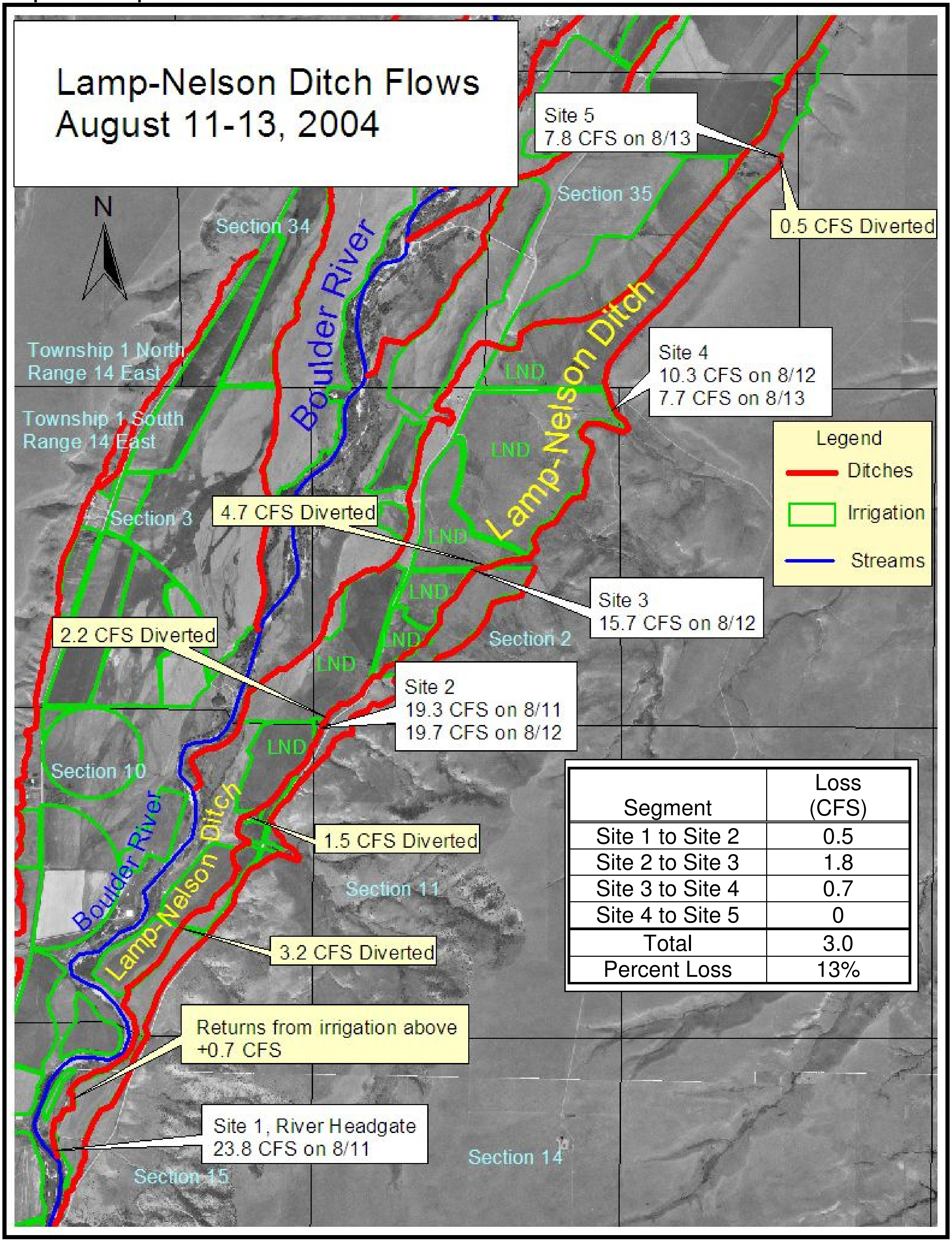
Segment	Loss (CFS)
Site 1 to Site 2	1.1
Site 2 to Site 3	2.5
Site 3 to Site 4	1.3
Site 4 to Site 5	.3
Site 5 to Site 6	2.5
Site 6 to Site 7	.2
Site 7 to Site 8	.7
Site 8 to Site 9	.4
Total	9
Percent Loss	40%

Map C-11. Clause-Weaver Ditch Flows.

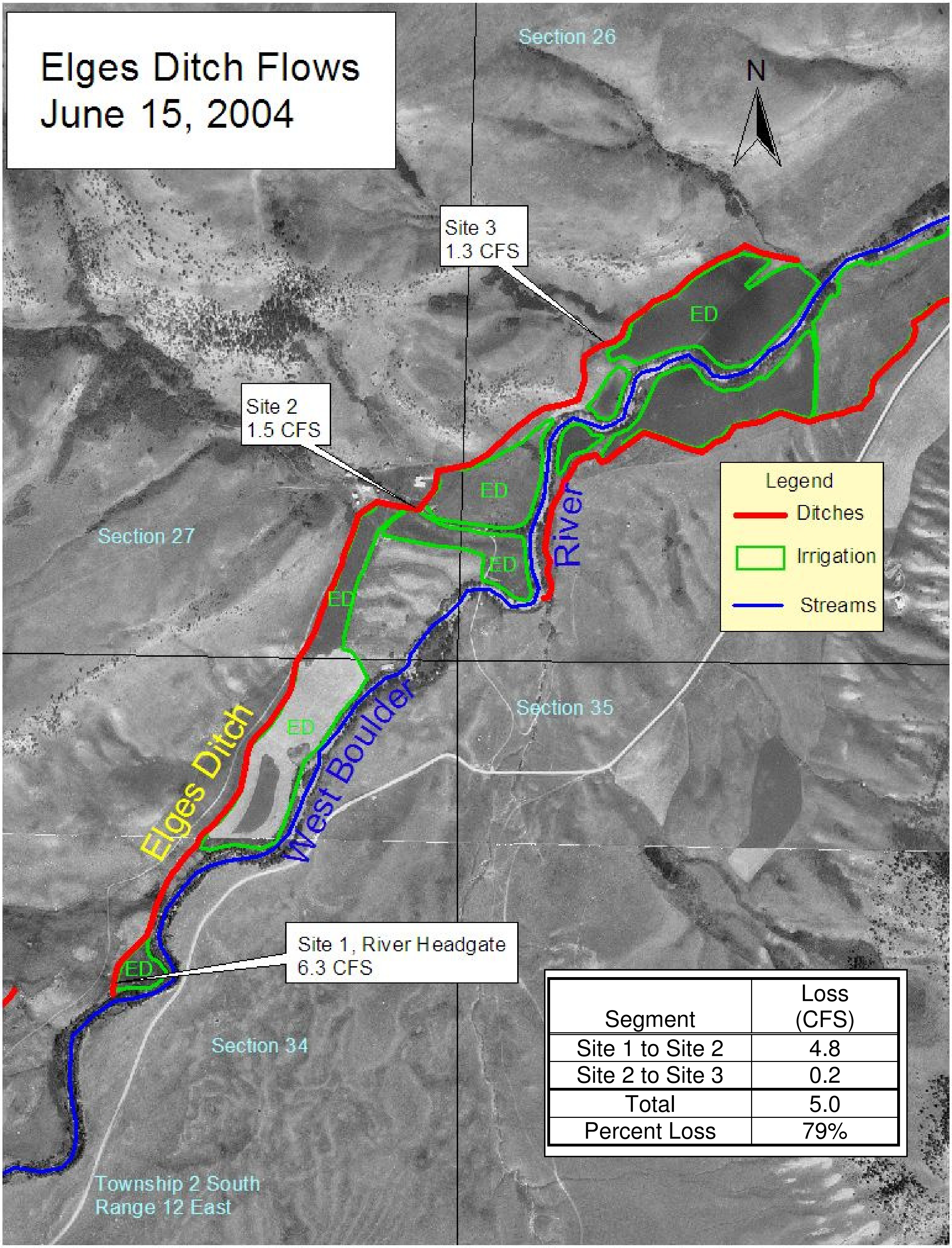


Segment	Loss (CFS)
Site 1 to Site 2	1.3
Total	1.3
Percent Loss	38%

Map C-12. Lamp-Nelson Ditch Flows.



Map C-13. Elges Ditch Flows.



Segment	Loss (CFS)
Site 1 to Site 2	4.8
Site 2 to Site 3	0.2
Total	5.0
Percent Loss	79%

Appendix D: Field Irrigation Efficiency Assessments.

Engle Field 1 Irrigation Efficiency Assessment Summary

Field Efficiency

Area irrigated by set: 1.1 acres
Duration of Set: 8 hours
Time for water to reach lower end of field: 5 hours
Volume of water applied: .71 acre-feet
Rate of application: 0.9 - 1.2 cubic feet per second; 36 - 48 inches
Tail-water leaving the field: 0.19 acre-feet
Tail-water flow rate: 0 to 0.75 cubic feet per second; 0 to 30 inches
Soil-water deficit prior to irrigation: 3.3 inches
Inches of Water applied: 7.8
Inches to satisfy soil water deficit: 3.3
Inches to tail-water loss: 2
Inches to deep percolation: 2.5
Overall field efficiency: 42%

Soil Characteristics

Type: Loam: 0-6”, clay to clay loam: 6-24”, clay: >24”
Approximate available water capacity: to 3 feet: 4.3 inches
Infiltration rate from soil survey: moderate
Measured cylinder infiltration rates: 6 to 8 inches per hour

Notes: Good loam top soil for first 6 inches. Below that, soil gets stony with a high clay content. Couldn’t initially get the soil auger deeper than about 18”, but was able to do so following irrigation.

Engle Field 2 Irrigation Efficiency Assessment Summary

Field Efficiency

Area irrigated by set: .75 acres
Duration of Set: 4.5 hours
Time for water to reach lower end of field: 3 hours
Volume of water applied: 1.4 acre-feet
Rate of application: 3.8 - 4.1 cubic feet per second; 150 - 160 inches
Tail-water leaving the field: 0.18 acre-feet
Tail-water flow rate: 0 to 1.8 cubic feet per second; 0 to 72 inches
Soil-water deficit prior to irrigation: 4.1 inches
Inches of Water applied: 23
Inches to satisfy soil water deficit: 4.1
Inches to tail-water loss: 2.9
Inches to deep percolation: 16
Overall field efficiency: 18%

Soil Characteristics

Type: Sandy clay loam: 0-12”, clay loam: 12-18”, loam: 18-24”, sandy clay loam: 24-36”
Approximate available water capacity: to 3 feet: 5.6 inches
Infiltration rate from soil survey: moderate
Measured cylinder infiltration rates: 6 to 12 inches per hour

Notes: At about 1 foot, the soil gets clayey, but at about 1.5 foot it gets sandier again. Soil becomes stony at about 2 feet.

Stenberg Irrigation Efficiency Assessment Summary

Field Efficiency

Area irrigated by set: .30 acres
Duration of Set: 2.5 hours
Time for water to reach lower end of field: 45 minutes
Volume of water applied: .535 acre-feet
Rate of application: 2.5 - 2.7 cubic feet per second; 110 - 120 inches
Tail-water leaving the field: 0.125 acre-feet
Tail-water flow rate: 0 to .96 cubic feet per second; 0 to 38 inches
Soil-water deficit prior to irrigation: 4 inches
Inches of Water applied: 21.7
Inches to satisfy soil water deficit: 4
Inches to tail-water loss: 5.1
Inches to deep percolation: 12.7
Overall field efficiency: 18%

Soil Characteristics

Type: Sandy loam: 0-12”, sandy clay loam: 12-24”, clayey loam: 24-30”,
Approximate available water capacity: to 2.5 feet: 4 inches
Infiltration rate from soil survey: moderate
Measured cylinder infiltration rates: 2 to 7 inches per hour

Notes: Soil is stony on top, especially at the upper end of the field. Mr. Stenberg says the field has been scraped, leveled and reworked throughout the years.

Brownlee Irrigation Efficiency Assessment Summary

Field Efficiency

Area irrigated by set: .48 acres
Duration of Set: 4 hours
Time for water to reach lower end of field: 1.5 hours
Volume of water applied: 1.2 acre-feet
Rate of application: 3.5 cubic feet per second; 140 inches
Tail-water leaving the field: 0.23 acre-feet
Tail-water flow rate: 0 to .81 cubic feet per second; 0 to 32 inches
Soil-water deficit prior to irrigation: 4.3 inches
Inches of Water applied: 29.4
Inches to satisfy soil water deficit: 4.3
Inches to tail-water loss: 5.7
Inches to deep percolation: 19.4
Overall field efficiency: 15%

Soil Characteristics

Type: Sandy loam topsoil, gravelly loamy sand subsoil at about 18”
Approximate available water capacity: to 3 feet: 4.3 inches
Infiltration rate from soil survey: moderate to rapid
Measured cylinder infiltration rates: 4 to 15 inches per hour

Notes: The Soil is sandy and takes water quickly. The water holding capacity of the soil also is relatively low. It would take frequent irrigations to keep the soil moisture high enough to meet crop demands.

Ellison Irrigation Efficiency Assessment Summary

Field Efficiency

Area irrigated by set: .76 acres
Duration of Set: 9 hours
Time for water to reach lower end of field: 2 hours, 45 minutes
Volume of water applied: 1.09 acre-feet
Rate of application: 1.5 cubic feet per second; 60 inches
Tail-water leaving the field: 0.20 acre-feet
Tail-water flow rate: 0 to .7 cubic feet per second; 0 to 28 inches
Soil-water deficit prior to irrigation: 4 inches
Inches of Water applied: 17
Inches to satisfy soil water deficit: 4
Inches to tail-water loss: 3
Inches to deep percolation: 10
Overall field efficiency: 23%

Soil Characteristics

Type: Loam to Clay Loam
Approximate available water capacity: to 3 feet: 5.6 inches
Infiltration rate from soil survey: Moderate
Measured cylinder infiltration rates: 5 to 8 inches per hour

Notes: It might be possible to reduce the set time to 6 hours and still achieve irrigation goals or, as an alternative, to increase the set length.